FOR OFFICIAL USE ONLY
File D 52.41/Liberty/225

McCOOK FIELD REPORT, SERIAL No. 1696

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV February 15, 1922 No. 301

LIBERTY STORAGE BATTERY ENDURANCE TEST

(POWER PLANT SECTION REPORT)

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 19, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.

By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

LIBERTY STORAGE BATTERY ENDURANCE TEST.

OBJECT.

The object of this test was to determine the endurance of the Standard Liberty engine storage battery on initial charge and on recharge, operating both distributors and operating one distributor, new, properly charged "Exide" batteries being used.

RESULTS.

The results of the tests are given in condensed form in the following table:

Battery.	Time.		Voltage.			Amperes.		
	To first miss hr./min.	To end of test hr./min.	Start.	First miss.	End of test.	Start.	First miss.	End of test.
A. First charge, operating both distributor heads.	3.39	4.07	8.2	5.12	4.4	1.3	1.7	1.45
B. First charge, operating both distributor heads.	2.00	3.26	8.1	6.30	4.85	1.5	2.1	1.6
A. Recharge, operating both distributor heads....	3.14	3.36	8.15	5.20	4.25	1.2	1.6	1.3
B. Recharge, operating both distributor heads....	3.54	4.00	8.25	5.80	4.50	1.3	1.8	1.4
C. First charge, operating left head............	9.36	10.35	8.25	5.40	4.75	1.35	.76	.75
D. First charge, operating right head............	9.36	10.35	8.25	4.88	3.20	1.55	.76	.50

Tests stopped when operation became so irregular as to endanger the engine.

CONCLUSIONS.

The test shows little difference in endurance between the first charge and the recharge of the Liberty battery. Operating a single distributor, the endurance of the battery is about 170 per cent greater than when operating both distributors.

METHOD OF TEST.

The batteries tested were new "Exide" Standard Liberty storage batteries, made by the United Storage Battery Co., Philadelphia. The batteries were taken from storage and properly charged to full capacity before test.

A Standard Liberty 12-cylinder engine mounted on a torque stand was used for this test. Double throw switches were used, wired so that the engine could be operated either on a regular battery or on the test battery. During all the runs the generator was cut out of the circuit, the current for ignition being furnished by the batteries alone. Ammeters and voltmeters were placed in the circuit so that the condition of the battery could be observed. After warming up the engine on the regular battery, the full throttle engine speed with distributors operating separately and together, was taken at the beginning of the runs, first using a regular Liberty battery in good condition and then the test battery. The throttle was then set to give an engine-propeller speed of 1,500 revolutions per minute (corresponding to the usual cruising engine speed) and the run continued on the test battery until it was necessary to stop the engine due to irregular running, the time of the first miss being carefully noted. Readings of the current and voltage supplied by the test battery or batteries, in addition to the regular readings of brake load, revolutions per minute, water temperatures, oil temperatures, and oil pressure, were taken every 15 minutes. By switching to the regular Liberty battery, it could be determined whether or not irregularities in the running were due to the condition of the test battery. Before each run the spark plug and breaker gaps were checked and set to 0.015 inches and 0.020 inches, respectively.

RESULTS OF TESTS.

The results of the test are shown in condensed form in the preceding table, and the readings taken are shown on pages 4 and 5. There seems to be little difference as regards endurance between the first charge and the recharge of the batteries tested. When operating both distributors with one battery, the missing started when the voltage had dropped to an average value of 5.6 volts, and the operation became too irregular to continue when the voltage had dropped to an average value of 4.5 volts. With separate batteries operating each distributor, the first missing occurred when the voltage had dropped to 5.15 volts and it was necessary to stop the engine when the voltage had dropped to an average of 4 volts. When operating a single distributor the battery lasted about 170 per cent longer than when operating two distributors and functioned when the voltage had dropped considerably lower.

These results apply only to batteries in first-class condition and fully charged. The endurance of the average battery in service will be much less than that obtained during this test.

Battery endurance test.

RUN No. 1.—TEST BATTERY "A" (FIRST CHARGE).

Battery operating both distributors.

Time.	Revolution per minute, both heads.	Corr. H.P.	Volts.	Amperes.
8.30	[1] 1,630	411.2	8.2	1.3
8.32	[2] 1,620	408.6	8.1	1.5
8.34	[3] 1,640	419.1	8.0	2.6
8.36	[4] 1,551	317.4	7.9	2.7
8.51	1,483	299.8	7.9	2.7
9.06	1,480	299.2	7.9	2.7
9.21	.....	.....	7.8	2.7

Stopped 9.22; motor missing: plugs fouled, No. 6 left; replaced all A.C. plugs with champion plugs.

9.50	1,493	304.2	7.8	2.70
10.05	1,492	301.6	7.8	2.70
10.20	1,490	298.8	7.8	2.70
10.35	1,495	302.1	7.7	2.65
10.50	1,498	299.1	7.65	2.65
11.05	1,504	304.0	7.60	2.60
11.20	1,500	302.0	7.50	2.60
11.35	1,502	301.1	7.45	2.55
11.50	1,501	299.8	7.25	2.50
12.05	1,504	301.5	7.20	2.45
12.20	1,494	293.3	6.60	2.30
12.35	1,453	277.0	5.12	1.70

First missing at 12.37.

12.50	1,389	251.0	4.80	1.60
1.05	.....	.....	4.40	1.45

Stopped 1.05, operation became too irregular.

Time to first miss, 3 hours. 39 minutes; time to end of test, 4 hours 7 minutes; revolutions per minute at start on standard cells, full throttle—left distributor, 1,640; right distributor, 1,630; both distributors, 1,645.

[1] Operating on left distributor only, full throttle.

[2] Operating on right distributor only, full throttle.

[3] Operating on both distributors, full throttle.

[4] From this point on engine ran with throttle set to give approximately 1,500 revolutions per minute.

RUN No. 2.—TEST BATTERY "B" (FIRST CHARGE).

Battery operating both distributors.

Time.	Revolution per minute, both heads.	Corr. H.P.	Volts.	Amperes.
8.45	[1] 1,625	400.6	8.1	1.50
8.47	[2] 1,630	403.2	8.1	1.45
8.49	[3] 1,650	421.6	8.0	2.75

8.51 stopped to install champion plugs.

9.10	[4] 1,500	298.2	8.00	2.75
9.25	1,499	296.8	7.90	2.70
9.40	.....	.....	7.85	2.70

9.48 stopped, fouled plug in No. 6 R. cylinder.

9.55	1,508	301.1	7.80	2.70
10.10	1,506	299.4	7.70	2.70
10.25	1,511	298.0	7.55	2.60
10.40	1,506	302.0	7.25	2.45
10.55	1,498	294.1	6.70	2.25
11.10	1,490	291.3	6.30	2.10

First missing at 11.11, No. 6 R.

11.25	1,482	277.6	5.95	1.80
11.40	1,484	275.4	5.65	1.80
11.55	1,476	274.1	5.45	1.80
12.10	1,468	265.3	5.20	1.75
12.25	.....	.....	4.85	1.60

Stopped 12.37.

Time to first miss, 2 hours; time to end of test, 3 hours 26 minutes; revolutions per minute at start on standard cells, full throttle—left distributor, 1,640; right distributor, 1,635; both distributors, 1,650.

[1] Operating on left distributor only, full throttle.

[2] Operating on right distributor only, full throttle.

[3] Operating on both distributors, full throttle.

[4] From this point on engine ran with throttle set to give approximately 1,500 revolutions per minute.

RUN No. 3.—TEST BATTERY "A" (RECHARGED).

Battery operating both distributors.

Time.	Revolutions per minute, both heads	Corr. H.P.	Volts.	Amperes.
8.45	[1] 1,660	413.0	8.15	1.2
8.47	[2] 1,650	413.3	8.15	1.2
8.49	[3] 1,675	430.5	8.00	2.2

8.51 stopped to install champion plugs.

9.10	[4] 1,506	298.0	8.0	2.40
9.25	1,504	296.0	8.0	2.40
9.40	1,504	296.0	7.95	2.40
9.55	1,506	300.2	7.90	2.35
10.10	1,503	300.9	7.85	2.30
10.25	1,503	295.0	7.80	2.30
10.40	1,498	296.3	7.75	2.30
10.55	1,505	296.4	7.70	2.30
11.10	1,511	296.4	7.65	2.30
11.25	1,506	300.4	7.55	2.30
11.40	1,505	297.6	7.45	2.30
11.55	1,502	295.8	7.25	2.25
12.10	1,493	293.4	6.25	1.80
12.25	1,398	264.9	5.20	1.60

First missing at 12.18 number 6L.

12.40	....	....	4.25	1.30

Stopped at 12.40.

Time to first miss, 3 hours 14 minutes; time to end of test, 3 hours 35 minutes; revolutions per minute at start on standard cells, full throttle—left distributor, 1,665; right distributor, 1,655; both distributors, 1670.

[1] Operating on left distributor only, full throttle.
[2] Operating on right distributor only, full throttle.
[3] Operating on both distributors, full throttle.
[4] From this point on engine ran with throttle set to give approximately 1,500 revolutions per minute.

RUN No. 4.—TEST BATTERY "B" (RECHARGED).

Battery operating both distributors.

Time.	Revolutions per minute, both heads	Corr. H.P.	Volts.	Amperes.
9.10	[1] 1,660	401.0	8.25	1.30
9.12	[2] 1,660	401.0	8.25	1.30
9.14	[3] 1,670	418.5	8.10	2.45

9.16 stopped to install champion plugs.

9.35	[4] 1,495	287.0	8.10	2.60
9.50	1,506	290.5	8.00	2.60
10.05	1,512	289.1	8.00	2.50
10.20	1,503	284.9	7.95	2.45
10.35	1,502	285.9	7.90	2.45
10.50	1,500	288.0	7.85	2.45
11.05	1,493	283.0	7.80	2.45
11.20	1,493	287.4	7.75	2.45
11.35	1,505	291.5	7.65	2.40
11.50	1,513	295.5	7.60	2.40
12.05	1,512	292.8	7.55	2.40
12.20	1,506	289.2	7.45	2.35
12.35	1,510	288.7	7.35	2.30
12.50	1,495	283.3	7.20	2.30
1.05	1,500	288.0	7.00	2.25
1.20	....	....	5.80	1.80

First missing at 1.23 number 6R.

1.29	....	....	4.50	1.40

Stopped 1.29.

Time to first miss, 3 hours 54 minutes; time to end of test, 4 hours; revolutions per minute at start on standard cells, full throttle—left distributor, 1,660; right distributor, 1,665; both distributors, 1,675.

[1] Operating on left distributor only, full throttle.
[2] Operating on right distributor only, full throttle.
[3] Operating on both distributors, full throttle.
[4] From this point on engine ran with throttle set to give approximately 1,500 revolutions per minute.

RUN No. 5.—TEST BATTERIES "C" AND "D" (FIRST CHARGE).

Batteries operating separate distributors.

Time.	Revolutions per minute, both heads.	Corr. H. P.	Test battery "D," right distributor.		Test battery "C," left distributor.	
			Volts.	Amperes.	Volts.	Amperes.
8.30	[1] 1,655	401.0	....	....	8.25	1.35
8.32	[2] 1,665	404.8	8.25	1.55	....	....
8.34	[3] 1,685	423.5	8.20	1.45	8.20	1.35

8.36 stopped to install champion spark plugs.

8.55	[4] 1,505	277.8	8.25	1.50	8.20	1.40
9.10	1,506	280.4	8.20	1.45	8.20	1.35
9.25	1,503	282.4	8.20	1.45	8.15	1.35
9.40	1,506	280.3	8.20	1.45	8.15	1.35
9.55	1,506	283.1	8.20	1.45	8.15	1.35
10.10	1,506	283.1	8.20	1.45	8.15	1.35
10.25	1,507	280.8	8.20	1.40	8.10	1.30
10.40	1,506	283.1	8.15	1.40	8.10	1.30
10.55	1,498	278.9	8.15	1.40	8.10	1.30
11.10	1,504	278.8	8.10	1.40	8.05	1.30
11.25	1,501	279.6	8.10	1.40	8.05	1.30
11.40	1,502	282.1	8.05	1.40	8.00	1.30
11.55	1,506	281.8	8.05	1.40	8.00	1.30
12.10	1,499	282.8	8.00	1.40	8.00	1.30
12.25	1,500	281.8	8.00	1.40	7.95	1.30
12.40	1,510	281.2	8.00	1.35	7.90	1.25
12.55	1,512	283.3	7.95	1.35	7.90	1.25
1.10	1,506	283.5	7.90	1.35	7.85	1.25
1.25	1,502	280.2	7.90	1.35	7.85	1.25
1.40	1,502	282.6	7.85	1.35	7.80	1.25
1.55	1,499	283.3	7.85	1.35	7.75	1.25
2.10	1,494	278.6	7.80	1.35	7.65	1.25
2.25	1,498	282.0	7.80	1.35	7.65	1.25
2.40	1,496	284.0	7.75	1.35	7.50	1.25
2.55	1,495	287.5	7.65	1.35	6.50	1.10
3.10	1,496	292.8	7.65	1.35	6.30	1.00
3.25	1,498	294.3	7.65	1.30	6.10	.95
3.40	1,500	297.1	7.60	1.30	5.95	.90
3.55	1,504	297.8	7.55	1.30	5.80	.90
4.10	1,498	294.2	7.50	1.30	5.75	.85
4.25	1,499	299.4	7.45	1.30	5.70	.85
4.40	1,505	306.9	7.38	1.30	5.65	.80
4.55	1,509	307.6	6.60	1.15	5.60	.80
5.10	1,519	309.6	6.10	1.10	5.60	.80
5.25	1,507	302.4	6.00	1.00	5.58	.80
5.40	1,506	309.6	5.75	.90	5.53	.80
5.55	1,504	301.7	5.50	.80	5.50	.80
6.10	1,498	305.4	5.20	.80	5.42	.80
6.25	1,500	303.4	4.88	.76	5.40	.76

First miss at 6.25.

6.40	1,493	292.0	4.30	0.70	5.38	0.76
6.55	1,487	306.8	3.55	.55	5.31	.76
7.10	....	....	3.40	.50	5.20	.76
7.24	....	....	3.20	.50	4.75	.75

Stopped at 7.24.

Time to first miss, 9 hours 36 minutes; time to end of test, 10 hours 35 minutes.

Revolutions per minute at start on standard cells, full throttle: Left distributor, 1,655; right distributor, 1,665; both distributors, 1,690.

[1] Operating on left distributor only, full throttle.
[2] Operating on right distributor only, full throttle.
[3] Operating on both distributors, full throttle.
[4] From this point on engine ran with throttle set to give approximately 1,500 revolutions per minute.

File D 52.415/23 *McCOOK FIELD REPORT, SERIAL No. 1697*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV February 15, 1922 No. 302

FIFTY-HOUR ENDURANCE FLIGHT TEST OF AUXILIARY STARTING DEVICE (BUZZER STARTER) FOR THE LIBERTY ENGINE

(POWER PLANT SECTION REPORT)

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
June 24, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.

By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

FIFTY-HOUR ENDURANCE FLIGHT TEST OF AUXILIARY STARTING DEVICE (BUZZER STARTER) FOR THE LIBERTY ENGINE.

OBJECT OF TEST.

The object of this test was to determine the durability of the "buzzer" starter in actual flight service.

CONCLUSIONS.

As finally revised, the Liberty engine "buzzer" starter appears to be sufficiently strong for actual service. It is simple, light, and fairly positive in action. It is recommended for installation on all service airplanes whose propeller is accessible from the ground.

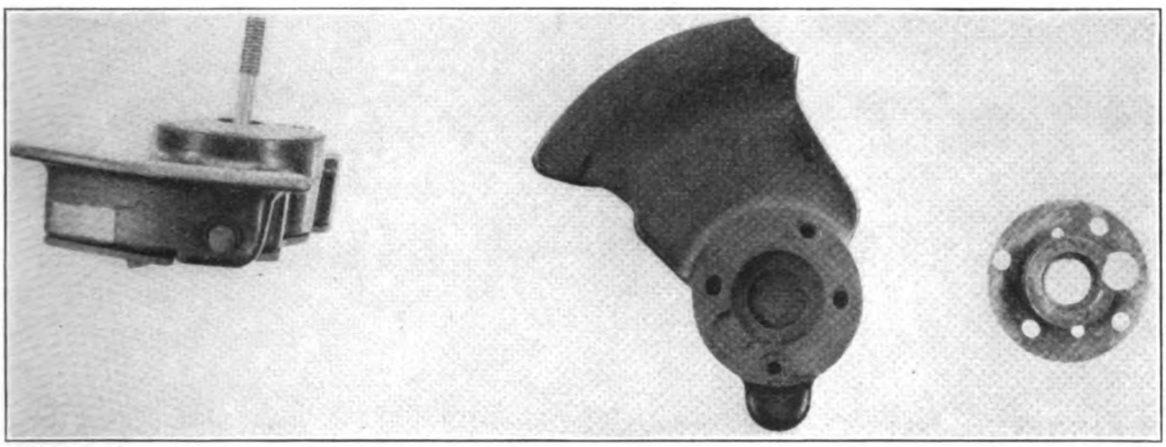


FIG. 1—"Buzzer" starter. Failures in service.

DESCRIPTION.

A "buzzer" starter assembly was installed in an airplane on a standard 12-cylinder Liberty engine. (A full description of the "buzzer" starter system and its operation during the laboratory tests is incorporated in Air Service Information Circular, Vol. II, No. 111.) The airplane was placed in service and a record of the number of starts was made. The actual number of hours flown was also recorded. No special tests were conducted. Two rotor failures occurred during the flight tests of the starter. One was due to the poor method of attaching the driving plate to the rotor casting. The second failure was probably due to a crack in the bakelite, which permitted a leak from the main rotor finger to the trailing finger. Figure 1 shows the nature of these failures.

The "buzzer" starter used for this test was flown for 57 hours and 51 minutes and used to start the engine 154 times. The starter is still in service and has been the cause of no complaint.

The "buzzer" starter rotor as now manufactured will probably not fail, since the driving plate is securely impregnated in the bakelite casting. The body of the rotor arm is also undercut between the main and trailing finger to eliminate the electrical leakage, which caused one of the failures of the system.

Several of the starters are now in daily use in airplanes of the Engineering Division and are giving complete satisfaction.

87413 22

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | February 15, 1922 | No. 303

DISCUSSION OF AIRPLANE TIRES AND WHEELS

(MATERIAL SECTION REPORT No. 150)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
September 8, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

DISCUSSION OF AIRPLANE TIRES AND WHEELS.

The tires and wheels used on the undercarriage of airplanes present a somewhat different problem from automobile tires and wheels. The wheel on an airplane is simply used in taking off and in landing. In the air it acts as a parasitic resistance and affects adversely the performance of the airplane. The airplane wheel must have a high strength-weight ratio, must be of sufficient diameter to permit landing on rough ground, and large enough to sustain the impact load due to average pancake landings. This has led to the exclusive use of a wire wheel.

The tire should also have a high strength-weight ratio, together with a high resistance to side thrust to prevent rolling off of the rim. The wear, which is an important consideration in automobile tires, is not so important in airplane tires, as the actual mileage is very low. Therefore the tread is thin, but the carcass must be strong and light weight. The function of an airplane tire is also that of a shock absorber, and the tire deflects considerably under load, which causes severe rim cutting if the tire is not properly designed.

When the American program of aircraft construction was started in 1917, there was only meager information and knowledge available as to the requirements and performance of the several wheels and tires to be used on airplanes of different weights. The chief source of information was the reports of actual service performance in Europe during the aeronautical development resulting from the World War. In view of the desire and need for interchangeability of parts with English and French planes, the current European practice was literally copied without any testing in this country. While this procedure was warranted in the face of the needs of the time, nevertheless it forced an "undesirable" on the aeronautic industry of the United States in the shape of clincher tires and wheels.

Due to low scale of production of airplanes and, therefore, lack of funds for experimental purposes, the clinchers have persisted, although changes are under way at present to adopt straight side tires and wheels throughout, or at least on all except the smallest sizes. This movement was in large part due to the Tire and Rim Association, with the active cooperation of the Engineering Division of the Air Service.

At the present time the clincher wheels and tires most commonly used are: 26 by 3 inches; 26 by 4 inches; 650 by 75 millimeters; 700 by 100 millimeters; 750 by 125 millimeters; 800 by 150 millimeters; 900 by 200 millimeters.

It will readily be seen that the European wheels, as indicated by the metric dimensions, were standardized with respect to the wheel diameter. This may or may not be of advantage in the field, but it certainly has the advantage of standardization, which is of considerable assistance to both the wheel and tire manufacturer. The American sizes, indicated by the English units, have not been standardized in any way, due probably to the lack of activity or development along aeronautic lines up to the time of America's entry into the war.

WHEEL DESIGNS.

In general, the clincher wheels are of two types: The English or Palmer type and the standard clincher type.

The English or Palmer type has a special rim contour, a special type of spoke lacing, and the wheel hub is offset rather than centered. All of these features can be seen in the accompanying diagram.

The standard clincher type has a rim of the S. A. E. contour, has the hub centered, is not cross laced as in the above, and the spokes are tangential to the hub.

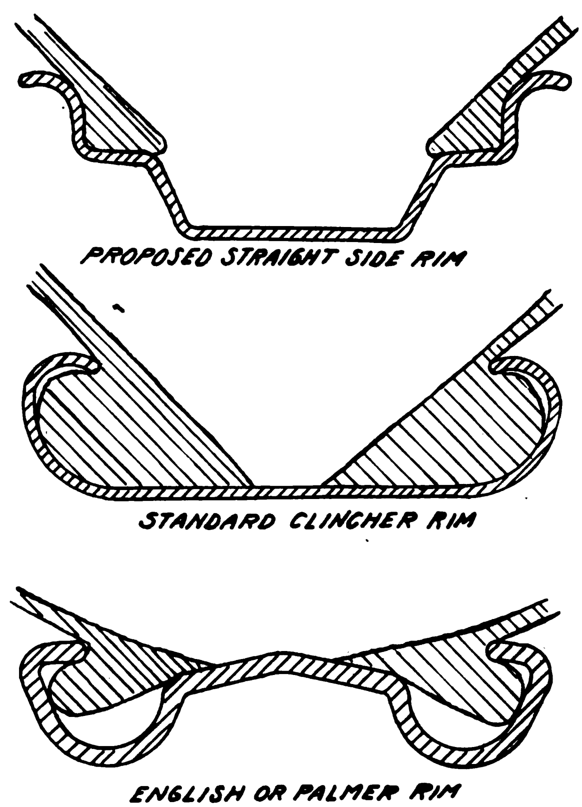


FIG. 1.—Sections of wheel rims and tire beads.

RIMS.

A discussion of the merits of the two types of wheel design would be concerned first with a consideration of rim contours. The Palmer type supports the tire bead only at the toe and the upper part of the heel. There are numerous claims made regarding the superiority of the performance of such a rim design when there is a side load on the tire and wheel. The fact that the heel of the exe bead is not supported, is supposed to permit of some flexibility to the bead when the tire is under a side load, and thereby lessen the chance of blow-out due to rim cutting. Nothing has ever been shown to indicate that such an effect really occurs, and it is the opinion of the writer that there is not a great deal of reliability in such claims.

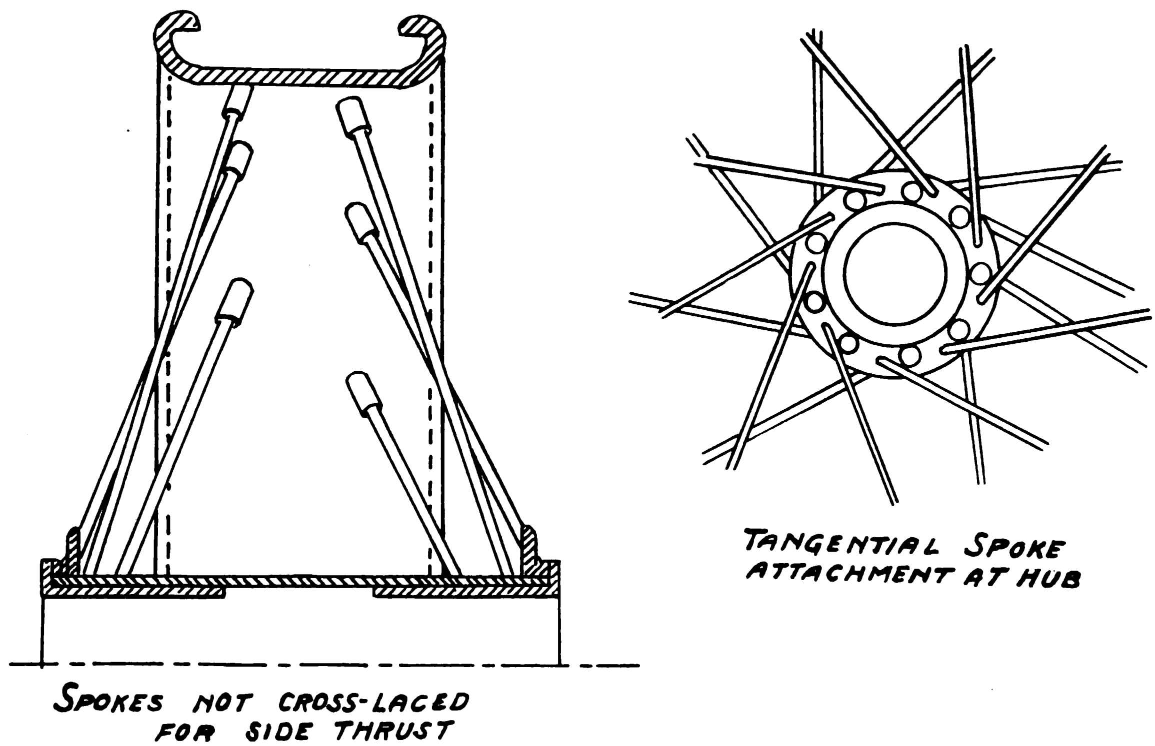


FIG. 2.—Standard clincher wheel.

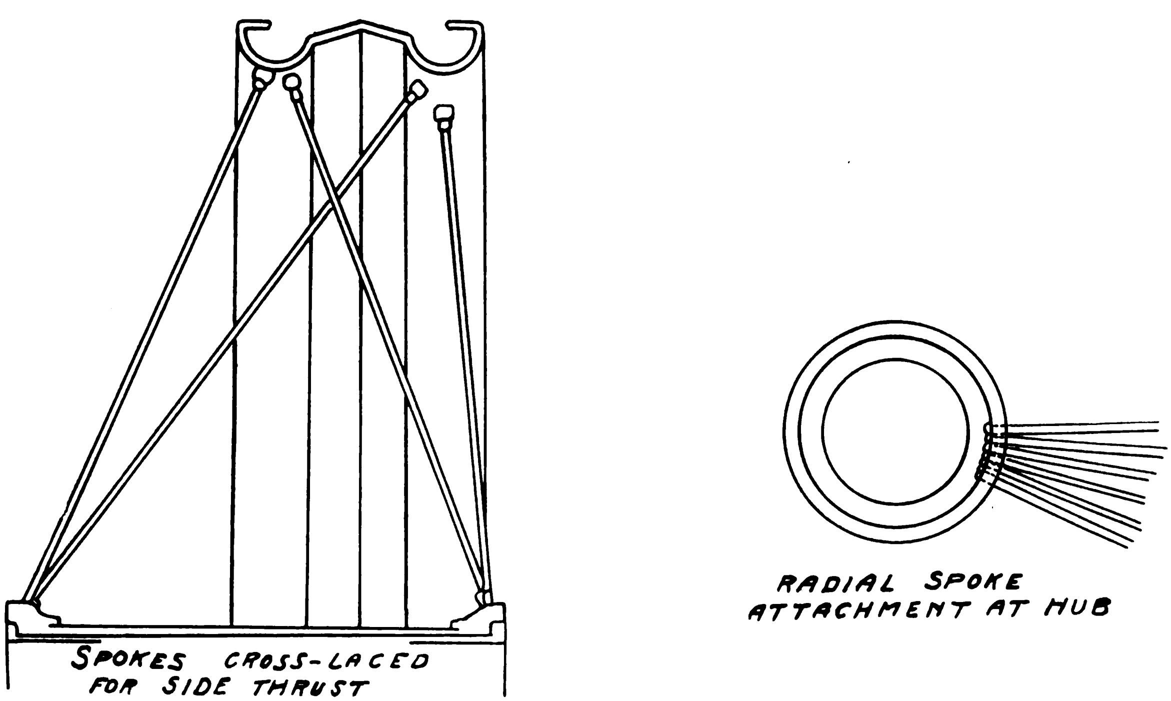


FIG. 3.—English or Palmer wheel.

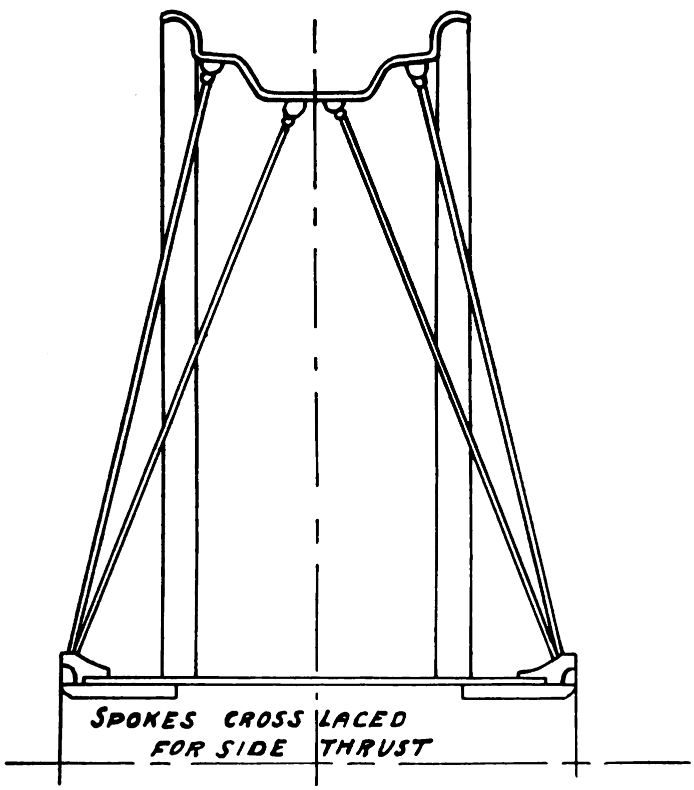
The standard clincher rim permits of a firm seat of the bead from the bead heel to the toe at all points. This bead seat seems to be a much more reasonable arrangement of a tire bead and certainly admits of a maximum in bead support. In the case of sudden side loading, it would be more satisfactory if the bead could be so seated on the rim as to insure more or less freedom, but it is a question if such a condition has been attained in the Palmer type of rim.

WHEEL LACING.

The Palmer type of cross lacing of the wheel spokes is a feature which should be incorporated in airplane wheels. It permits of strong bracing for side thrust, which, in the case of airplane wheels, is very necessary. In the American standard clincher wheel there is no cross lacing of the spokes, and the desirable feature of bracing for side thrust is neglected.

in the case of automobile wheels. If an airplane wheel were driven—that is, if movement to the plane were transmitted by gearing through the wheels, there might be some justification for the use of the tangential method, but such is not the case, and, in addition, this type of attachment prohibits any possibility of cross-lacing for side thrust, therefore, all things considered, it is believed that for use on airplanes, the radial type of spoke attachment is superior to the tangential method.

The Palmer type wheels all have a considerable offset to the hub, the idea being, it is presumed, to increase the bracing effect for side thrust. No doubt the construction is theoretically correct, but a stress analysis of several wheels of this type showed a considerable eccentricity which would not add to the general efficiency of the wheel in service. In the case of a wheel with the hub centered, there would be no eccentricity, but the effect of bracing for side thrust would be slightly less than in a wheel of the Palmer type.



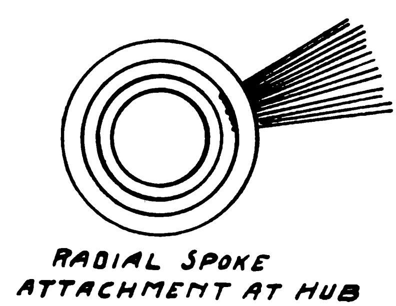


FIG. 4.—New straight side wheel.

HUB ATTACHMENT.

There are two general methods of attaching the spokes to the hubs, radially and tangentially.

The radial attachment is self-explanatory in that the spoke is attached directly to the hub flange and extends to the rim in a straight line. When a load is applied to such a spoke, it functions as a column with both ends fixed, and the load normal to the column axis, or as a straight tension member depending upon its position in the wheel.

In the tangential attachment the spoke extends from the wheel rim to a point tangent to the hub. The tangential type of lacing makes the wheel heavier than the radial type, because this method necessitates a 90° bend in the spoke at the point of attachment to the hub. This type of lacing is similar to the method of hub attachment

TIRES.

Airplane tires differ from automobile tires in weight and tread construction. The carcass is composed of plies of frictioned cord fabric laid in the usual way. There is no cushion or breaker strip used, and the tread is of high-grade tread stock of $\frac{1}{8}$ inch thickness. The side walls and the bead are constructed in essentially the same manner as automobile tires.

PHYSICAL TESTS OF WHEELS.

Accurate information regarding the performance of the wheels used, both in the field and in the laboratory, was necessary and essential for the general development of new wheels and tires, and more important still for the information of the designer. It was with these facts in

view that extensive laboratory tests were run on all the available clincher wheels and tires, as well as all available sizes of the new straight side type of the proposed new schedule.

The physical tests in the laboratory were confined largely to static loading to determine the wheel deformation under load and the ultimate load of the wheel.

The testing machine and the nature of the test rigging were about as follows:

An Olsen 50,000-pound capacity test machine was used. A 4-inch dirt surface in a suitable container was placed on the stationary head of the test machine and the wheel to be tested was placed upon it in a vertical position. The tire, deflated, was allowed to remain mounted on the wheel during the test. An axle was mounted in the hub and the load was applied to the wheel from the pulling head of the test machine through straps to the axle in the wheel. This test rigging is shown in figure 5.

There are several very good reasons why the wheel was mounted on a tightly packed dirt surface. The earlier methods of wheel testing required that a wooden block be fitted to the wheel rim at the load point. In this case, the wheel failure would evidence itself by the rim bending at the ends of the fitted wooden block. The breaking load of the wheel varied with the length of the block fitted to the rim. In the case where the wheel, without the tire, was simply mounted on the head of the test machine, the first failure was in a distortion of the rim contour and finally a rim failure at the load point. Neither of these failures was typical of a wheel failure in service, and it was with this point in mind that the final test rig was decided upon. With the tire on the wheel, but deflated, and the whole supported by a tightly packed dirt surface, a failure was obtained which resembled in every way the failure which was observed under service conditions.

In obtaining information regarding the wheel deformation under load, radial measurements were made from the hub to the rim at various stages of the static test for breaking load. In general, the distortion of the wheel tends from a circle to an ellipse, with a slight lowering of the hub below the intersection of the main axes of the ellipse. This tendency is slight but will probably explain why all of the spokes, except those immediately in the plane of the load point, are under a tension load.

The main determinations made in this series of tests are indicated in the following table:

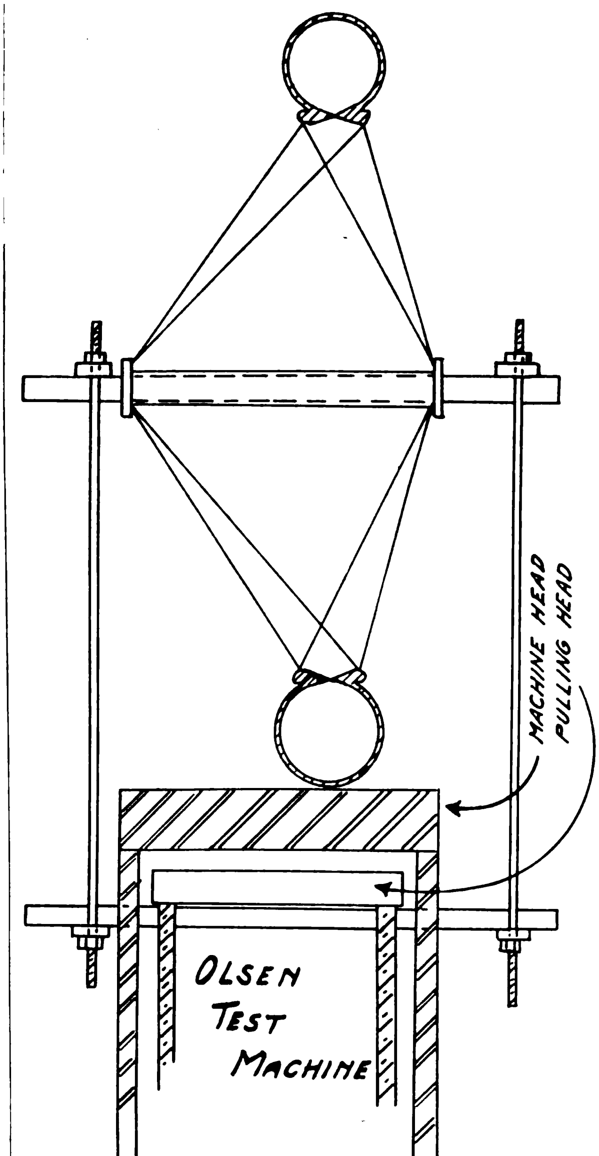


FIG. 5.—Static test rig for airplane wheels and tires.

Physical features of airplane wheels.

	26 by 4 inch	28 by 4 inch.	750 by 125 millimeter.	800 by 150 millimeter.	36 by 8 inch.	44 by 10 inch.
Gage of rim....inches..	0.080	0.095	0.092	0.125	0.125	0.175
Gage of spokes....do....	0.112	0.105	0.105	0.105	0.135	0.150
Number of spokes....	40	52	64	64	80	80
Weight of wheel....pounds..	8	10	12	15	25	66
Breaking load....do....	7.500	7.500	10.000	13.000	18.000	33.000
Tire and tube weights....do....	9.5	11	12	12	33	74
Hub length (inside)....inches..	6.0	5.6	7.25	7.25	6.75	9.63
Hub diameter (inside)....do....	1.5	1.5	2.38	2.38	2.56	3.19
Method of lacing....	Tangential	Radial.	Radial.	Radial.	Radial.	Radial.
Type of wheel....	Standard clincher.	Straight side.	Palmer.	Palmer.	Straight side.	Straight side.

DESIGNERS' LIMITATIONS.

In the design of airplanes to Government specifications, a certain factor of safety is prescribed. This factor varies with the part of the plane and also with the type of plane; thus, the factor for the wheels on a training plane is 7.0, while the factor on the wheels of a two-seater pursuit plane is 4.6. To assist the designer in this phase of his problem, the following table was compiled:

WHEEL LOADING.

Size.	Maximum allowable plane weight per wheel (pounds).
44 by 10 inches	6,500
36 by 8 inches; 900 by 200 millimeters	4,000
800 by 150 millimeters	2,500
750 by 125 millimeters	1,800
700 by 100 millimeters; 28 by 4 inches	1,200
26 by 4 inches	1,000

If the above maximum allowable weights are closely followed by the designer, satisfactory performance is assured, as these limits are indicated not alone in the laboratory, but in the field as well.

EQUIPMENT IN SERVICE.

It is interesting to note how closely the above table for maximum wheel loading checks with the load per wheel on a number of service airplanes.

The following table was compiled in determining if the various sizes of wheels and tires were overloaded:

Name.	Type.	Weight.	Wheels.	Weight per wheel.	Tire size.	Recommended weight.
		Pounds.		*Pounds.*	*Inches.*	*Pounds.*
Standard E-1	Single Seater	1,190	2	595	26 by 3	600
Thomas Morse S4C	do	1,374	2	*687	26 by 3	600
Loening Monoplane	Two Seater	2,600	2	1,300	26 by 4	1,000
Curtiss JN-4	do	2,050	2	*1,025	26 by 4	1,000
Vought VE-7	do	1,960	2	980	26 by 4	1,000
SE-5	Single Seater	2,060	2	*1,030	26 by 4	1,000
					Millimeters.	
Orenco	do	2,600	2	*1,300	700 by 100	1,200
Thomas Morse MB3	do	2,350	2	1,175	700 by 100	1,200
DH-4	Two Seater	4,000	2	*2,000	750 by 125	1,800
USD-9-A	do	4,800	2	*2,400	750 by 125	1,800
Bristol	do	2,645	2	1,325	750 by 125	1,800
Le Pere	do	3,660	2	*1,830	750 by 125	1,800
Pomilio	do	2,140	2	1,070	750 by 125	1,800
Le Pere Triplane	Multi-seater	7,130	4	1,780	750 by 125	1,800
XB-1-A	Two Seater	2,994	2	1,497	750 by 125	1,800
Armored Triplane	Multi-seater	9,740	4	2,435	900 by 200	4,000
Handley-Page	do	14,450	4	3,610	900 by 200	4,000
Martin Bomber	do	10,000	4	2,500	900 by 200	4,000
					Inches.	
Martin Bomber	do	10,000	2	5,000	44 by 10	6,500

NOTE.—The (*) indicates that the wheel is overloaded with respect to the recommended maximum wheel load. The most serious of these are the DH-4, the D-9-A, and the Le Pere, all of which are at present using a larger size tire than indicated in the above.

PHYSICAL TESTING OF TIRES.

The laboratory test of tires is concerned chiefly with determining the most satisfactory operating load and pressures. The tests involved in determining the quality of the material used in a tire are sufficiently well known to require little explanation. The quality of the tread stock, tire cords, and cements, the construction of the beads, including wire reinforcements, are all indicated to insure a tire of high quality, so that the chief problem to the designer is one of satisfactory and efficient tire operation.

In testing for "load-deflection" data, the test rigging is essentially the same as in determining the breaking load of the wheel. The wheel and inflated tire are mounted directly on the stationary head of the test machine. Stations are marked on the tire at the load point and along the side wall of the tire to the rim in the plane of the load. The location of the stations is determined at various degrees of tire deflection, and the contour of the tire at these points is plotted. From a study of these contours, it is possible to check the tire and rim construction to obtain the maximum in tire performance.

Attached are load-deflection curves for all of the present sizes of tires, at pressures of 50, 65, and 75 pounds, and from these one can safely interpolate for any intermediate pressure.

One point to bear in mind when using load-deflection curves is that the tire deflection, when the plane is resting normally on the ground, should be about 20 per cent. This figure was arbitrarily chosen as a result of recommendations made by the various tire manufacturers with reference to tire life for different degrees of normal tire deflection.

In designing undercarriages for airplanes, it is necessary to use the load-deflection curves in conjunction with the table showing the maximum allowable plane weight per wheel, if the greatest efficiency is to be obtained from the combination of wheel and tire.

CLINCHER VS. STRAIGHT SIDE.

A discussion of the relative merits of the above types has been exhaustively treated in connection with the manufacture of automobile tires. The conditions are essentially the same for the airplane tires, but they are much more aggravated than in the case of automobile tires.

The chief cause of failure in service of clincher tires has been blowouts due to rim cutting. In every case of blowout, due to reasons other than an airplane crash, more than 90 per cent of the failures are typical blow-outs. Another feature well worth mentioning is that in the case of a blowout of a tire mounted on a Palmer wheel with the offset hub, the blow-out occurred on the side of the wheel on which the hub is offset. Of course, the chief cause of rim cutting is under-inflation, and as practically all airplane tires must be slightly under-inflated, this condition will always obtain as long as clincher tires continue to be used. The peculiar feature about Palmer tires, mentioned above, is believed to be partly due to the eccentricity in the wheel, shown by the stress analysis of a wheel of this type, although the chief cause here is also underinflation

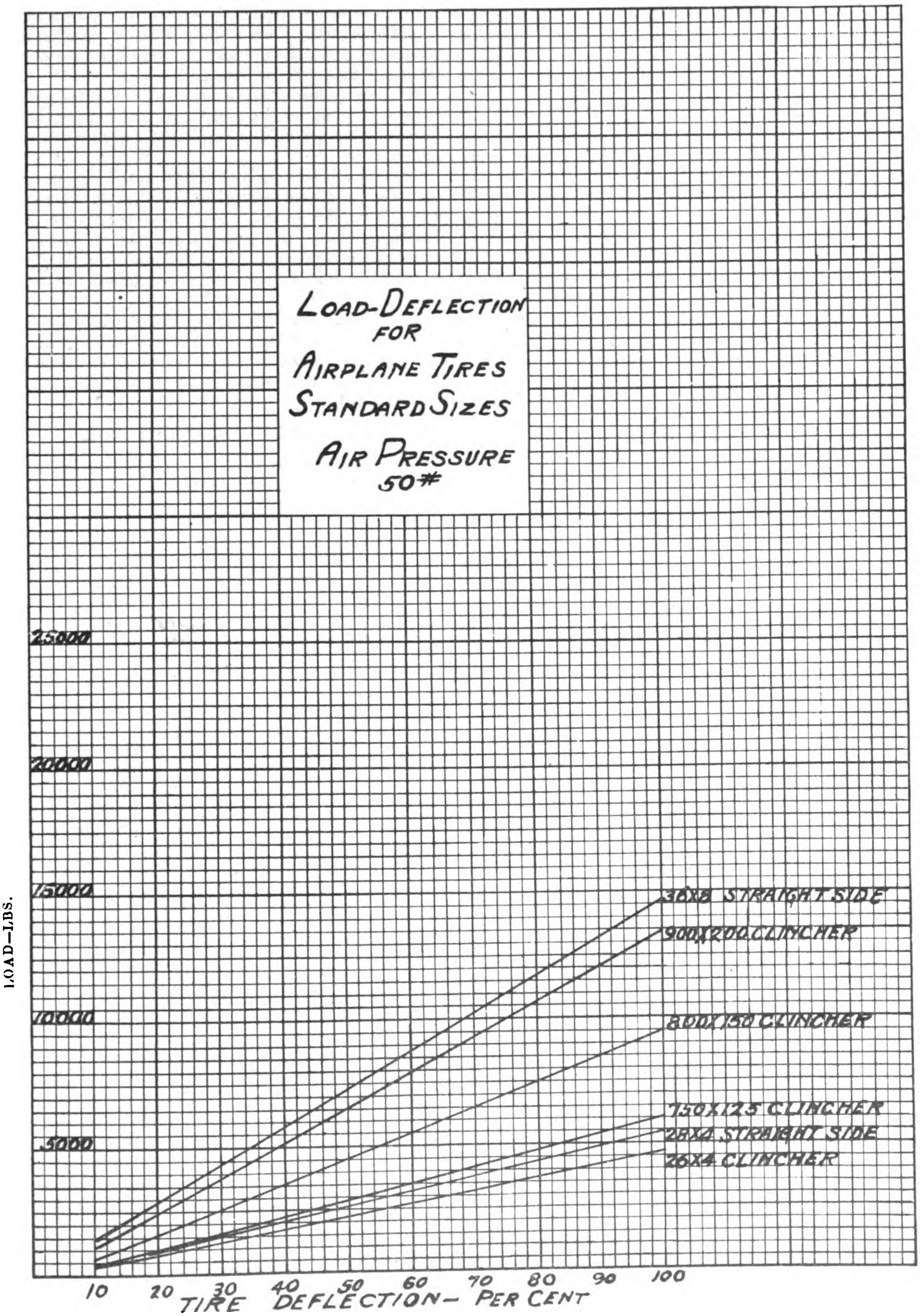

LOAD-DEFLECTION
FOR
AIRPLANE TIRES
STANDARD SIZES
AIR PRESSURE
50#
25000
20000
15000
10000
5000
LOAD—LBS.
36X8 STRAIGHT SIDE
900X200 CLINCHER
800X150 CLINCHER
750X125 CLINCHER
28X4 STRAIGHT SIDE
26X4 CLINCHER
10
20
30
40
50
60
70
80
90
100
TIRE DEFLECTION— PER CENT

FIG. 6.

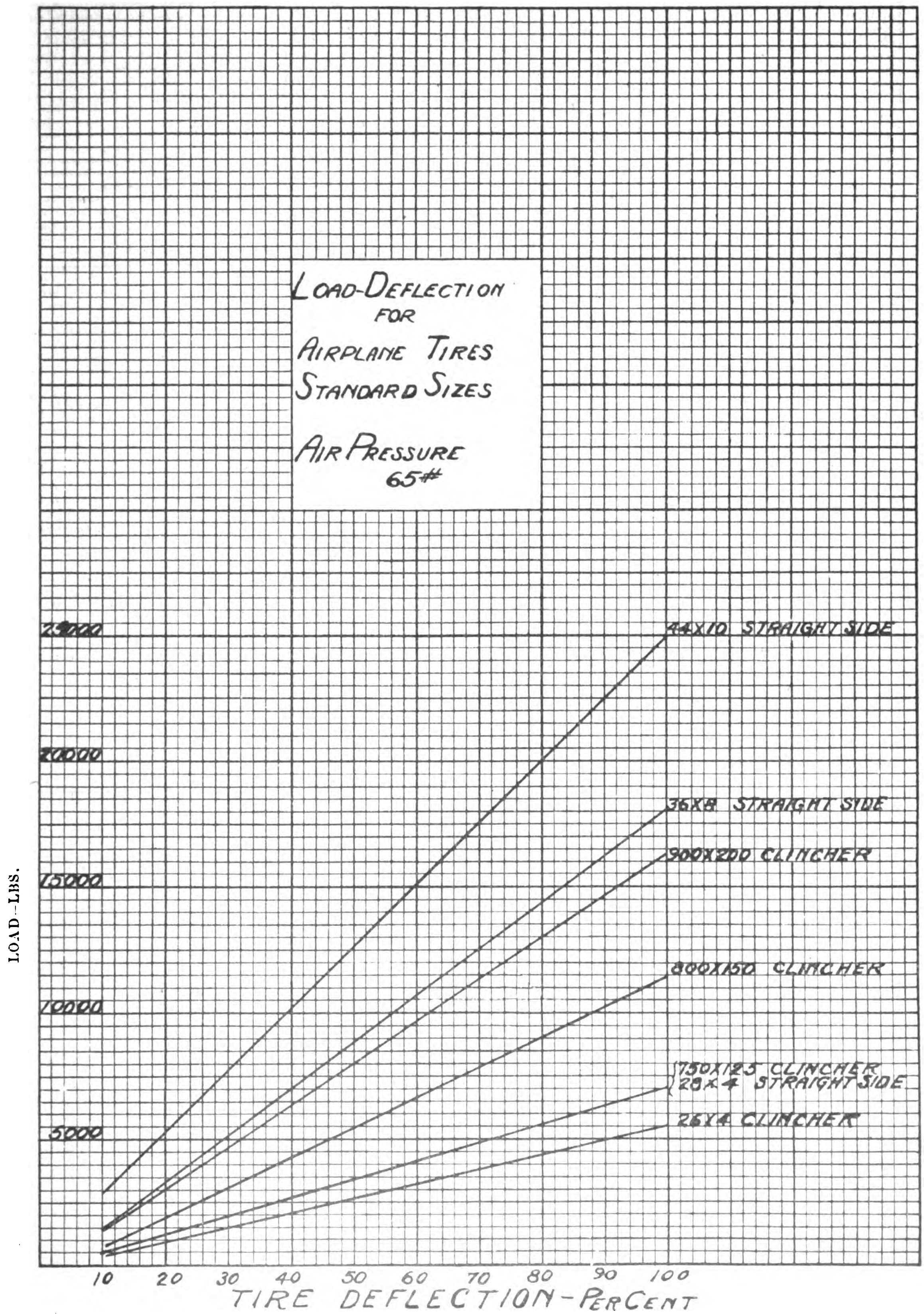

LOAD-DEFLECTION
FOR
AIRPLANE TIRES
STANDARD SIZES
AIR PRESSURE
65#
LOAD-LBS.
25000
20000
15000
10000
5000
44X10 STRAIGHT SIDE
36X8 STRAIGHT SIDE
900X200 CLINCHER
800X150 CLINCHER
750X125 CLINCHER
28X4 STRAIGHT SIDE
26X4 CLINCHER
10
20
30
40
50
60
70
80
90
100
TIRE DEFLECTION-PERCENT

FIG. 7.

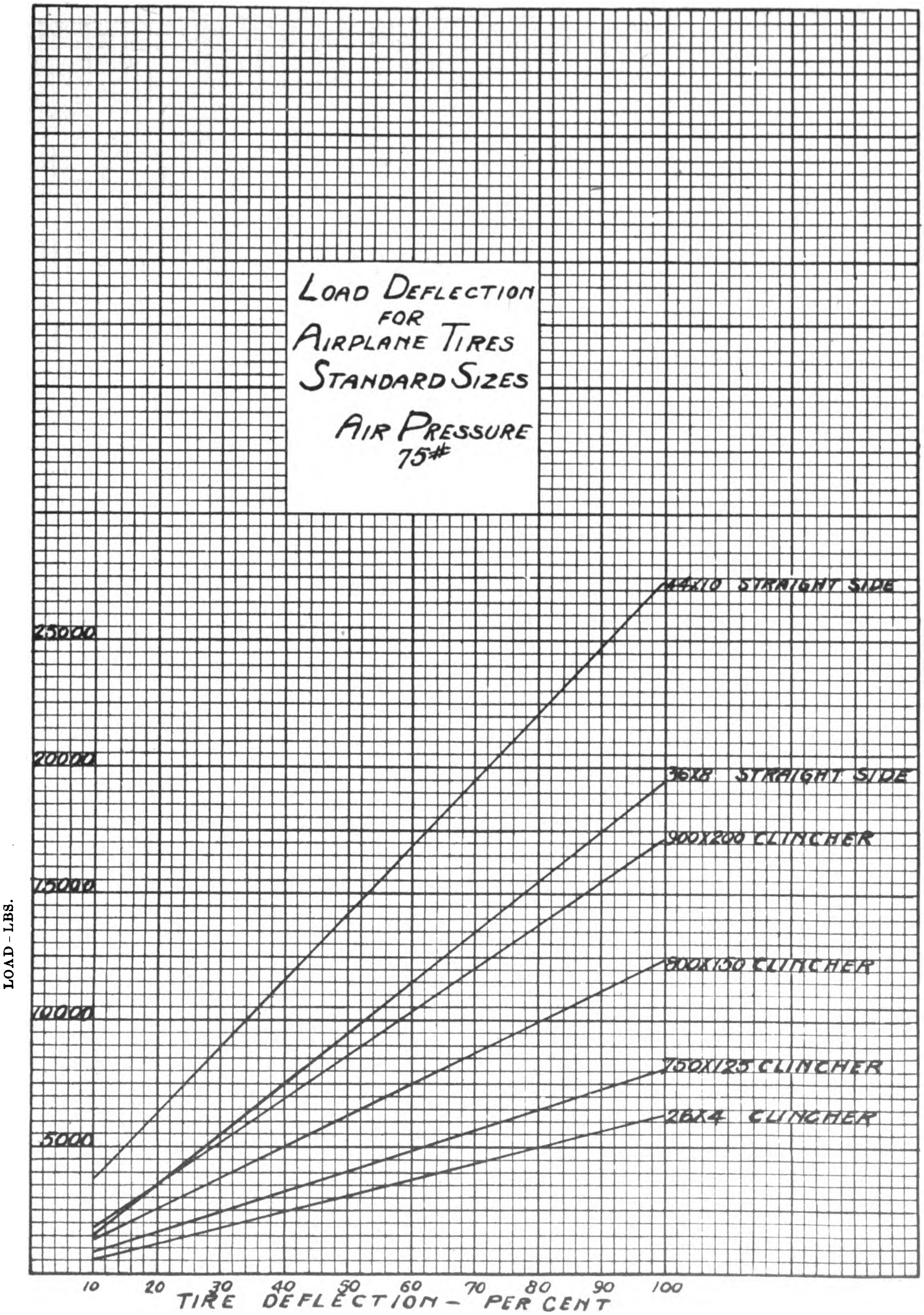

LOAD DEFLECTION
FOR
AIRPLANE TIRES
STANDARD SIZES
AIR PRESSURE
75#
44X10 STRAIGHT SIDE
36X8 STRAIGHT SIDE
900X200 CLINCHER
900X150 CLINCHER
750X125 CLINCHER
26X4 CLINCHER
25000
20000
15000
10000
5000
LOAD - LBS.
10
20
30
40
50
60
70
80
90
100
TIRE DEFLECTION - PER CENT

FIG. 8.

Straight-side tires will remedy this trouble due to rim cutting, and the only other objectionable phase would be that of rolling the tire off the rim, in the case of a sudden or heavy side load. This condition can be overcome by the use of a good steel in the rim, and by the proper design of the straight-side bead with steel wire reinforcing.

Another consideration in favor of the adoption of straight-side tires is that of ease of handling. A clincher tire is not easy to mount even on the smaller sizes, and in the larger sizes it is extremely difficult. It has been noted that usually four men are necessary to properly mount a 900 by 200 millimeter tire on a rim. In the case of the straight-side tire, one man very often can completely mount even the largest size tire of the straight-side type. No case requires more than two men.

PROPOSED STRAIGHT-SIDE SCHEDULE.

In view of all difficulty experienced in the maintenance of the clincher tires and wheels in the field, a program of straight-side wheels and tires was laid out, which is believed to incorporate the good features of both the clincher and straight-side types, and eliminates the bad features of both. In laying out the program, the following were borne in mind:

RIMS.

A one-piece rim with a drop center, as shown in figure 1, was chosen for lightness, simplicity, and ease of manufacture.

LACING OF SPOKES.

A type of lacing should be used which would permit of cross bracing for side thrust as far as possible.

HUBS.

The hub should be centered to overcome any eccentricity due to offsetting the hub in bracing for side thrust.

The sizes included in the program are the 3, 4, 5, 6, 7, 8, 10, and 12 inch sizes, and the wheel diameter is kept constant at 20 inches. The resulting tire sizes are: 26 by 3 inches, 28 by 4 inches, 30 by 5 inches, 32 by 6 inches, 34 by 7 inches, 36 by 8 inches, 40 by 10 inches, and 44 by 12 inches. In view of the difficulties consequent to a complete schedule change, it was decided to attempt to change only those sizes with which the greatest trouble was experienced. With this end in view, the 28 by 4 inch, the 32 by 6 inch, and the 36 by 8 inch sizes have been selected for preliminary tests. The 28 by 4 inch and the 36 by 8 inch have successfully passed laboratory and service tests, and from the data obtained from these tests it has been possible to make any necessary changes in the wheel design of the remaining wheels in the proposed schedule.

One new wheel, worthy of special mention, is a 44 by 10-inch wheel and tire used at present on the Glenn Martin bomber, of the type which has only two wheels in the undercarriage. The wheel is laced in essentially the same way as the proposed type, but the rim embodies the truck wheel feature of the removable side ring for ease of mounting and removing the tire. In fact, the rim is a truck rim which has been machined down to a thickness of 0.175 inch. Its other features are indicated in the foregoing table of "Physical features of airplane wheels."

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV September 15, 1922 No. 303 (Addendum)

ADDENDUM TO INFORMATION CIRCULAR, VOL. IV NO. 303, DISCUSSION OF AIRPLANE TIRES AND WHEELS

(MATERIAL SECTION REPORT)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
July 27, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

ADDENDUM TO INFORMATION CIRCULAR, VOL. IV, NO. 303—DISCUSSION OF AIRPLANE TIRES AND WHEELS.

PURPOSE.

To determine the load per square inch of tire contact on the supporting surface and its relation to the supporting load and tire inflation.

CONCLUSIONS.

The load which a tire will carry depends upon the area of contact and the inflation pressure, and is equal to the product of the area in square inches by the inflation pressure in pounds per square inch. The area of contact is the same for equal tire deflections regardless of the inflation pressure, but the load carried by the tire will be greater for the same area of contact as the pressure is increased.

The deflection of the tire is principally a flattening of the tread, and bears a simple mathematical relation to the area of contact. The area of contact is an ellipse equal to $\frac{\pi A B}{4}$, in which A and B are the major and minor axes of the ellipse. The length of these axes can be approximated closely from the formula for the chord subtended by the arc of the segment of a circle. The length of the chord is equal to twice the square root of the deflection multiplied by the difference between the diameter and the deflection, or

$$A=2\sqrt{h\,(d-h)}$$

d for the major axis is equal to the outside diameter of the wall and tire. *d* for the minor axis is equal to the diameter of the tire.

The loads for the 54 by 12 tire calculated on this basis for a 50 per cent deflection of the tire would be 10,000, 12,000, and 14,000 pounds for 50, 60, and 70 pounds per square inch inflation pressures, respectively.

APPARATUS.

The standard wheel and tire test rig was used in all cases, with the following change: A sheet of paper was placed between the tire and the supporting surface. Powdered soapstone was scattered on the paper to permit of obtaining the contact diagram of the tire when the load was applied. These contact diagrams were obtained for inflation pressures of 50 and 65 pounds and for tire deflections of 25 and 50 per cent.

MATERIALS.

The wheels and tires used were the new straight-side type of the following sizes: 28 by 4, 32 by 6, 36 by 8, and 44 by 10.

PROCEDURE.

The wheels with inflated tires mounted on them were mounted on the stationary head of an Olsen testing machine. Soapstone was scattered on paper between the supporting surface and the tire to record the diagram of tire contact with supporting surface. The contact diagram of each tire was obtained for deflections of 25 and 50 per cent at inflation pressure of 50 and 65 pounds. The area of the tire contact diagrams was obtained by means of a planimeter, and the pressure per square inch on the diagram was obtained from the load supported by the tire and the area of the diagram.

RESULTS OF TESTS.

Table 1 gives the results of tests and calculations obtained in this series of experiments.

In the case of airplane tires subjected to load there is always an increase in the inflation pressure as a result of tire deflection. While this increase is never very large, it is a measurable quantity, and the following table shows the general tendencies of pressure change in the several tires tested:

Size.	Initial pressure.	Pressure at 50 per cent deflection.
28 x 4	65	70
32 x 6	60	65
36 x 8	50	55
36 x 8	60	65
44 x 10	65	70

In Table 1 the column next to last is headed "Load recommended in designers' handbook." This value is obtained from the load-deflection curves for each size tire at the deflection and inflation pressures noted. The last column is the load per square inch calculated from area of contact diagram and the recommended loads. It can be seen that the calculated or service pressures are almost identical to those obtained in the laboratory, and these pressures are not excessive and are well within the working limits of the tire.

DISCUSSION OF RESULTS.

It will be seen from Table 1 that the load per square inch of contact on the supporting surface, as determined by the contact diagram, is the same as the inflation pressure of the tire. The load per inch of tread width is con-

siderably higher for high inflation pressures than for low pressures and varies with the different sizes of tires. It is not a satisfactory basis for calculating the load which a tire will carry.

The last two columns in Table 1 are included for general consideration. Previous to the laboratory determinations as obtained above, it was felt that it was necessary to indicate a "maximum allowable plane weight per wheel" for the guidance of designers. These limits were chosen from the load-deflection curves previously developed in this report, after deciding in a more or less arbitrary way that a normal tire deflection of approximately 20 per cent would permit of satisfactory tire performance.

It will be seen that the load per square inch of contact diagram area calculated from these maximum loading limits for designers checks very closely with the loading per square inch of contact diagram area as determined in the laboratory.

TABLE 1.

Tire.	Air pressure (pounds).	Deflection (per cent).	Load, (pounds).	Area contact diagram (square inches).	Short axis of diagram (inches).	Load per inch tread width (pounds).	Load per square inch contact area (pounds).	Load recommended in designers' handbook.	Load per square inch, recommended.
28 x 4	50	25	1,300	23.4	3.0	433	55.5	1,200	51.5
28 x 4	50	50	2,400	45.1	4.6	520	53.5	2,400	53.5
28 x 4	65	25	1,560	23.1	3.4	462	67.5	1,600	69.0
28 x 4	65	50	2,900	44.0	4.5	645	66.0	3,400	77.0
32 x 6	50	25	2,200	43.0	4.4	503	50.0	2,000	46.5
32 x 6	50	50	4,700	87.0	6.9	684	54.0	4,500	52.0
32 x 6	65	25	2,600	39.3	4.3	612	66.2	2,500	63.0
32 x 6	65	50	6,000	86.3	6.4	942	69.5	5,500	64.0
36 x 8	50	25	3,600	69.4	6.6	544	52.0	3,500	50.5
36 x 8	50	50	8,000	136.9	8.9	900	58.5	7,200	52.5
36 x 8	65	25	4,900	73.5	6.6	740	66.6	4,000	55.0
36 x 8	65	50	10,000	140.6	9.0	1,120	71.2	8,750	62.0
44 x 10	50	25	5,000	93.4	7.1.	704	53.5	6,000	65.0
44 x 10	50	34	8,320	150.2	9.1	913	55.5	9,000	60.0

McCOOK FIELD REPORT, SERIAL No. 1700

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | February 15, 1922 | No. 304

NOMOGRAPHIC COLUMN CHARTS

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 22, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

NOMOGRAPHIC COLUMN CHARTS.

The charts collected in this report have been constructed at different times since April, 1920, but have never before been published in a shape convenient for the use of designers. Several similar charts are found on pages 299 to 303 of "Structural Analysis and Design of Airplanes," but they suffer from certain defects. The size is too small for practical use. Certain standard sizes of tubing are omitted and certain sizes now no longer standard are shown. In order to get the large tubes on the figure the lines representing the small tubes are confusingly close together. These faults are eliminated in the set of charts given in this report.

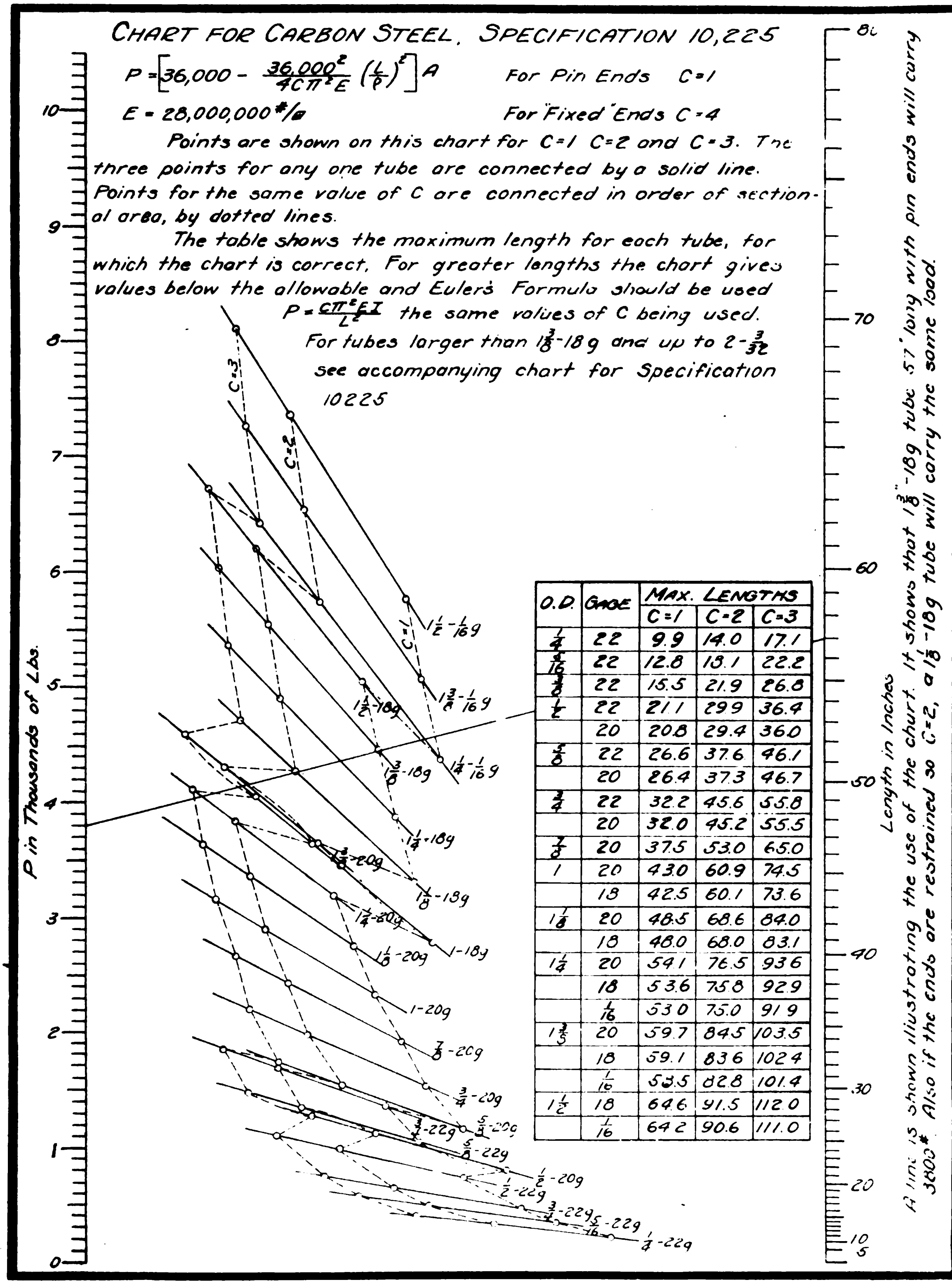
The method of using the charts is explained by the notes on them, especially the chart for small sizes of short columns of Specification 10225 steel. This chart can be recognized by the sloping line drawn across the chart and sloping upward to the right. The theory of their construction is given in Lipka's "Graphical and Mechanical Computation," Peddle's "The Construction of Graphical Charts," and d'Ocagne's "Traite' de Nomographie." By means of these charts it can be very quickly determined which one of a number of standard tubes should be used for a column when the compressive load, length, and fixity of the ends are known. Their use also makes much more certain the employment of standard sizes of tubes.

The following charts are contained in this report:

1. Short columns (Parabolic formula range). Specification 10225. Carbon steel tubing. Small size tubes.
2. Short columns. Specification 10225. Tubing. Large size tubes.
3. Short columns. Specification 10227. Alloy steel tubing. Small size tubes.
4. Short columns. Specification 10227. Tubing. Large size tubes.
5. Long steel columns (Euler formula range). Can also be used for long columns of duralumin.
6. Long spruce columns.

Sometime in the future, when the sizes of duralumin tubing have been standardized and a value chosen for the yield point, charts for short duralumin columns will be added.

The charts for 10227 tubing are based on a yield point of 90,000 pounds per square inch and can be used only as a general guide for tubes in which the yield point has been raised by a special heat treatment.



O.D.	GAGE	MAX. LENGTHS		
		C=1	C=2	C=3
$\frac{1}{4}$	22	9.9	14.0	17.1
$\frac{5}{16}$	22	12.8	18.1	22.2
$\frac{3}{8}$	22	15.5	21.9	26.8
$\frac{1}{2}$	22	21.1	29.9	36.4
	20	20.8	29.4	36.0
$\frac{5}{8}$	22	26.6	37.6	46.1
	20	26.4	37.3	46.7
$\frac{3}{4}$	22	32.2	45.6	55.8
	20	32.0	45.2	55.5
$\frac{7}{8}$	20	37.5	53.0	65.0
1	20	43.0	60.9	74.5
	18	42.5	60.1	73.6
$1\frac{1}{8}$	20	48.5	68.6	84.0
	18	48.0	68.0	83.1
$1\frac{1}{4}$	20	54.1	76.5	93.6
	18	53.6	75.8	92.9
	$\frac{1}{16}$	53.0	75.0	91.9
$1\frac{3}{8}$	20	59.7	84.5	103.5
	18	59.1	83.6	102.4
	$\frac{1}{16}$	58.5	82.8	101.4
$1\frac{1}{2}$	18	64.6	91.5	112.0
	$\frac{1}{16}$	64.2	90.6	111.0

Fig. 1.

87802—22

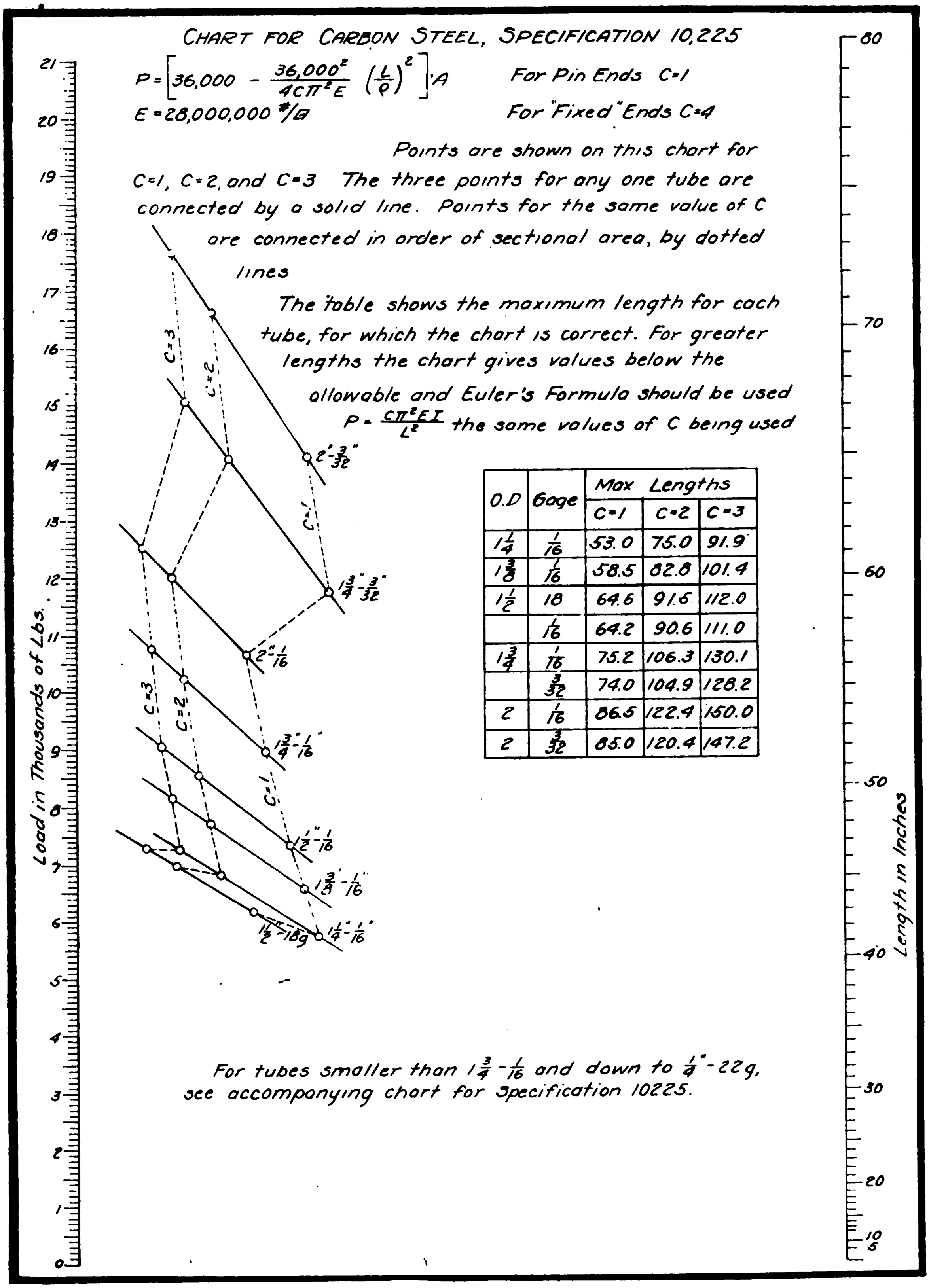


CHART FOR CARBON STEEL, SPECIFICATION 10,225

$$P=\left[36{,}000-\frac{36{,}000^2}{4C\pi^2E}\left(\frac{L}{\rho}\right)^2\right]A \qquad \text{For Pin Ends } C=1$$

$E=28{,}000{,}000$ #/□ For "Fixed" Ends $C=4$

Points are shown on this chart for $C=1$, $C=2$, and $C=3$. The three points for any one tube are connected by a solid line. Points for the same value of C are connected in order of sectional area, by dotted lines

The table shows the maximum length for each tube, for which the chart is correct. For greater lengths the chart gives values below the allowable and Euler's Formula should be used $P=\frac{C\pi^2EI}{L^2}$ the same values of C being used

O.D	Gage	Max Lengths		
		C=1	C=2	C=3
1¼	1/16	53.0	75.0	91.9
1⅜	1/16	58.5	82.8	101.4
1½	18	64.6	91.6	112.0
	1/16	64.2	90.6	111.0
1¾	1/16	75.2	106.3	130.1
	3/32	74.0	104.9	128.2
2	1/16	86.5	122.4	150.0
2	3/32	85.0	120.4	147.2

For tubes smaller than 1¾-1/16 and down to ¼"-22g, see accompanying chart for Specification 10225.

FIG. 2.

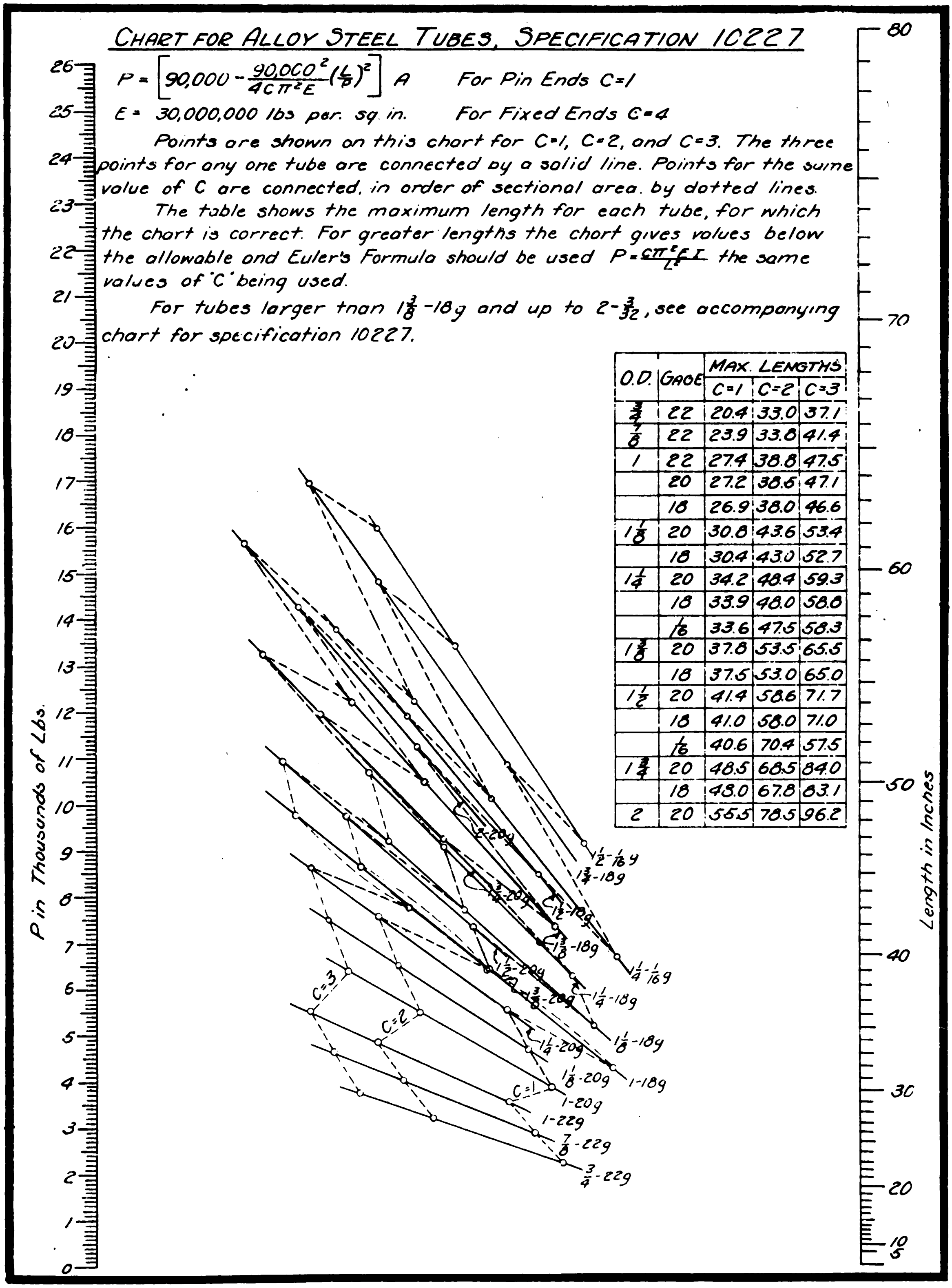


CHART FOR ALLOY STEEL TUBES, SPECIFICATION 10227

$$P = \left[90{,}000 - \frac{90{,}000^2}{4C\pi^2 E}\left(\frac{L}{\rho}\right)^2\right] A \qquad \text{For Pin Ends } C=1$$

$E = 30{,}000{,}000$ lbs per. sq. in. For Fixed Ends $C=4$

Points are shown on this chart for $C=1$, $C=2$, and $C=3$. The three points for any one tube are connected by a solid line. Points for the same value of C are connected, in order of sectional area, by dotted lines.

The table shows the maximum length for each tube, for which the chart is correct. For greater lengths the chart gives values below the allowable and Euler's Formula should be used $P = \frac{C\pi^2 EI}{L^2}$ the same values of "C" being used.

For tubes larger than $1\frac{3}{8}$-18g and up to 2-$\frac{3}{32}$, see accompanying chart for specification 10227.

O.D.	GAGE	MAX. LENGTHS		
		C=1	C=2	C=3
$\frac{3}{4}$	22	20.4	33.0	37.1
$\frac{7}{8}$	22	23.9	33.8	41.4
1	22	27.4	38.8	47.5
	20	27.2	38.6	47.1
	18	26.9	38.0	46.6
$1\frac{1}{8}$	20	30.8	43.6	53.4
	18	30.4	43.0	52.7
$1\frac{1}{4}$	20	34.2	48.4	59.3
	18	33.9	48.0	58.8
	$\frac{1}{16}$	33.6	47.5	58.3
$1\frac{3}{8}$	20	37.8	53.5	65.5
	18	37.5	53.0	65.0
$1\frac{1}{2}$	20	41.4	58.6	71.7
	18	41.0	58.0	71.0
	$\frac{1}{16}$	40.6	70.4	57.5
$1\frac{3}{4}$	20	48.5	68.5	84.0
	18	48.0	67.8	83.1
2	20	55.5	78.5	96.2

FIG. 3.

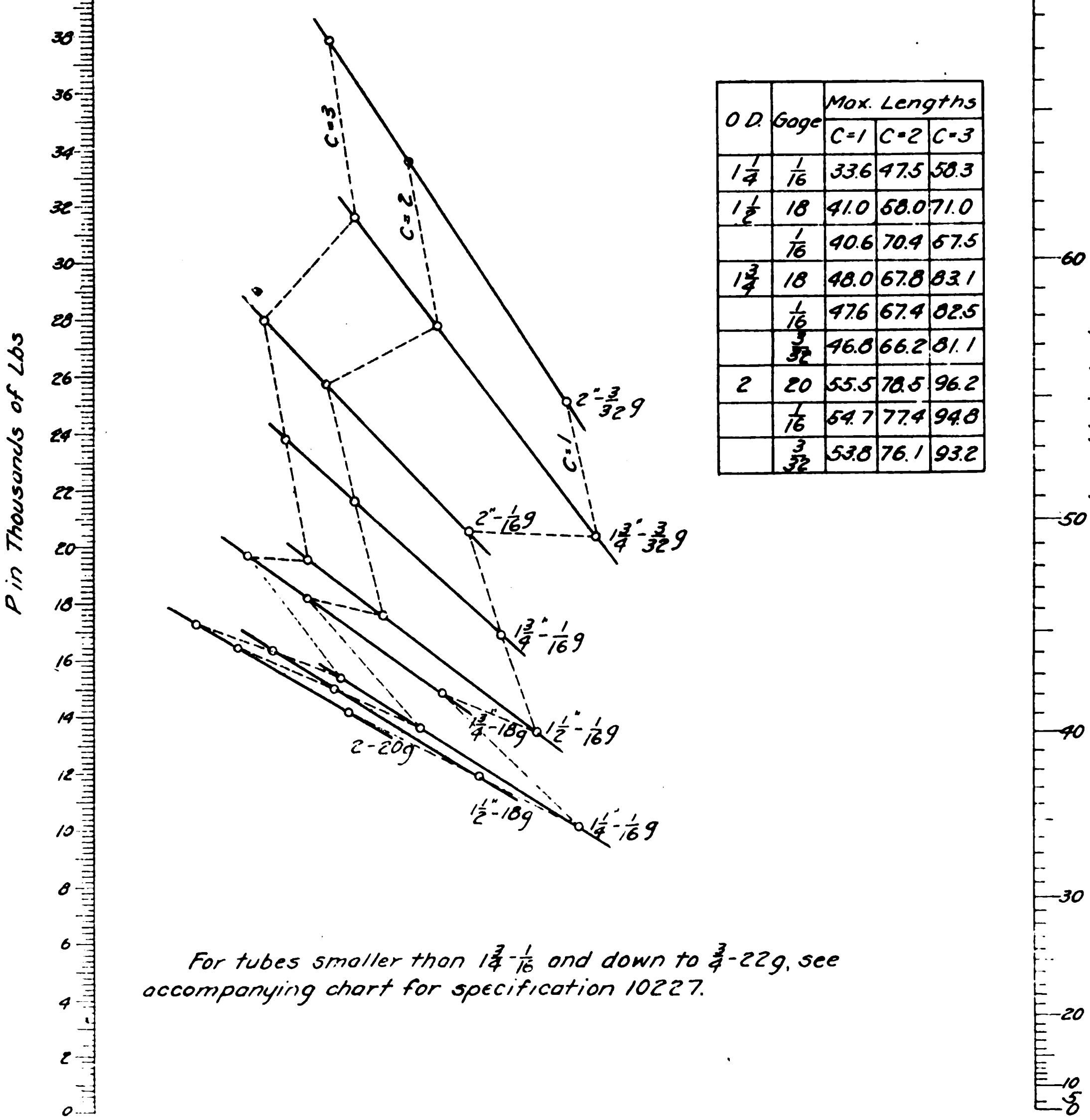
CHART FOR ALLOY STEEL TUBES, SPECIFICATION 10227

$P = \left[90{,}000 - \frac{90{,}000^2}{4C\pi^2E}\left(\frac{L}{\rho}\right)^2\right]A.$ For Pin Ends $C=1$

$E = 30{,}000{,}000$ lbs. per. sq. in. For Fixed Ends $C=4$

Points are shown on this chart for $C=1$, $C=2$, and $C=3$. The three points for any one tube are connected by a solid line. Points for the same value of C are connected, in order of sectional area, by dotted lines.

The table shows the maximum length for each tube, for which the chart is correct. For greater lengths the chart gives values below the allowable and Euler's Formula should be used. $P = \frac{C\pi^2EI}{L^2}$ the same values of C being used.



O.D.	Gage	Max. Lengths		
		C=1	C=2	C=3
$1\frac{1}{4}$	$\frac{1}{16}$	33.6	47.5	58.3
$1\frac{1}{2}$	18	41.0	58.0	71.0
	$\frac{1}{16}$	40.6	70.4	57.5
$1\frac{3}{4}$	18	48.0	67.8	83.1
	$\frac{1}{16}$	47.6	67.4	82.5
	$\frac{3}{32}$	46.8	66.2	81.1
2	20	55.5	78.5	96.2
	$\frac{1}{16}$	54.7	77.4	94.8
	$\frac{3}{32}$	53.8	76.1	93.2

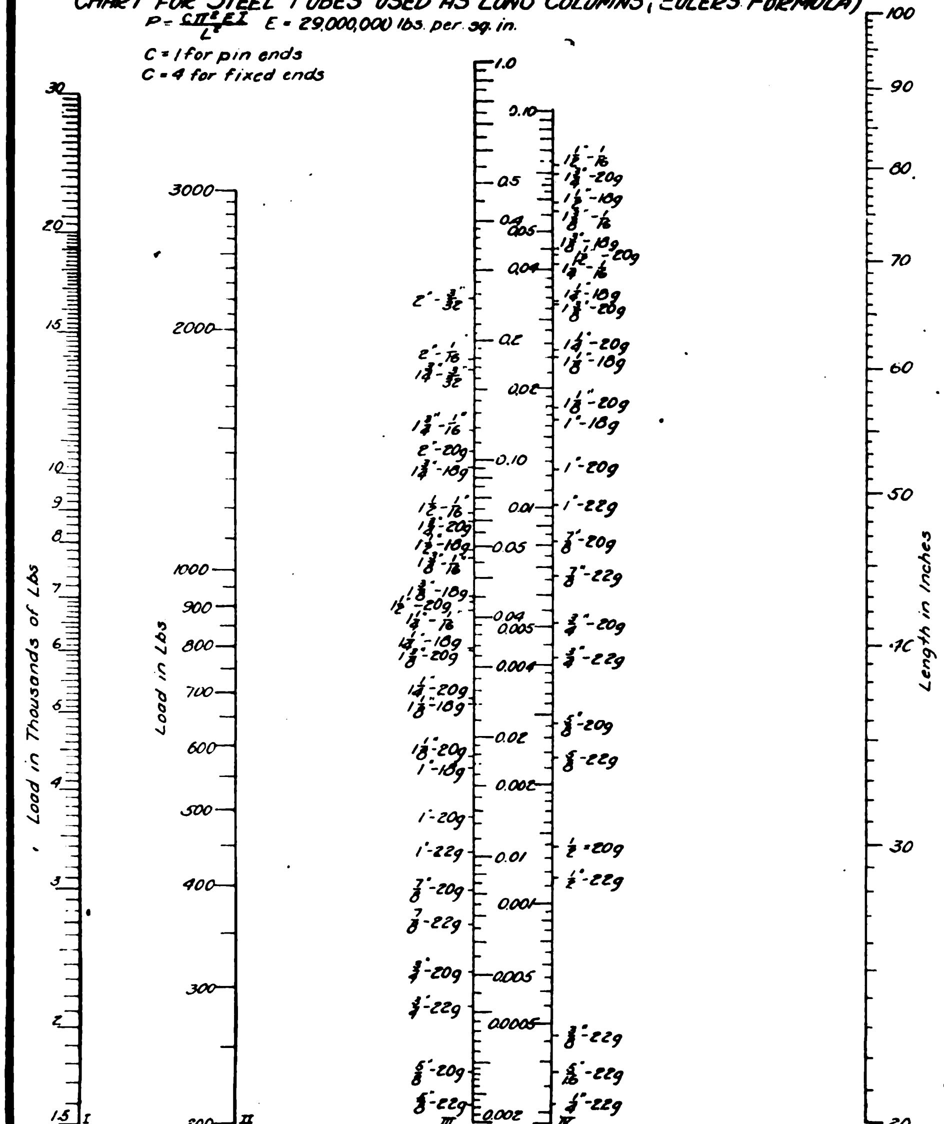
For tubes smaller than $1\frac{3}{4}-\frac{1}{16}$ and down to $\frac{3}{4}$-22 g, see accompanying chart for specification 10227.

FIG. 4.

CHART FOR STEEL TUBES USED AS LONG COLUMNS (EULER'S FORMULA)

$P = \frac{C\pi^2 EI}{L^2}$ E = 29,000,000 lbs. per sq. in.

C = 1 for pin ends
C = 4 for fixed ends



This chart is plotted for C=1. When C>1 multiply the value of P given on the chart by C

Do Not Use This Chart when L is Less than the value given in the tables in such cases use the charts for the parabolic formula $P = \left[f - \frac{f^2}{4C\pi^2 E}\left(\frac{L}{\rho}\right)^2\right]A$

The sizes given in the tables are in order of weight

Use scale I with scale III or scale II with scale IV

Scales III and IV are graduated on one side for Moments of Inertia, I

Specification 10225				
O.D	Gage	C=1	C=2	C=3
1/4	22	9.9	14.0	17.1
5/16	22	12.8	18.1	22.2
3/8	22	15.5	21.9	26.8
1/2	22	21.1	29.9	36.4
1/2	20	20.8	29.4	36.0
5/8	22	26.6	37.6	46.1
3/4	22	32.2	45.6	55.8
5/8	20	26.4	37.3	46.7
3/4	20	32.0	45.2	55.5
7/8	20	37.5	53.0	65.0
1	20	43.0	60.9	74.5
1 1/8	20	48.5	68.6	84.0
1 1/4	20	54.1	76.5	93.6
1	18	42.5	60.1	73.6
1 3/8	20	59.7	84.5	103.5
1 1/8	18	48.0	68.0	83.1
1 1/4	18	53.6	75.8	92.9
1 3/8	18	59.1	83.6	102.4
1 1/2	18	64.6	91.5	112.0
1 1/4	1/16	53.0	75.0	91.9
1 3/8	1/16	58.5	82.2	101.4
1 1/2	1/16	64.2	90.6	111.0
1 3/4	1/16	75.2	106.3	130.1
2	1/16	86.5	122.4	150.0
1 3/4	3/32	74.0	104.9	128.2
2	3/32	85	120.4	147.2

Specification 10227				
O.D	Gage	C=1	C=2	C=3
3/4	22	20.4	33.0	37.1
7/8	22	23.9	33.8	41.4
1	22	27.4	38.8	47.5
1	20	27.2	38.5	47.1
1 1/8	20	30.8	43.6	53.4
1 1/4	20	34.2	48.4	59.3
1	18	26.9	38.0	46.6
1 3/8	20	37.8	53.5	65.5
1 1/2	20	41.4	58.6	71.7
1 1/8	18	30.4	43.0	52.7
1 1/4	18	33.9	48.0	58.8
1 3/4	20	48.5	68.5	84.0
1 3/8	18	37.5	53.0	65.0
2	20	55.5	78.5	96.2
1 1/2	18	41.0	58.0	71.0
1 1/4	1/16	33.6	47.5	58.3
1 3/4	18	48.0	67.8	83.1
1 1/2	1/16	40.6	70.4	57.5
1 3/4	1/16	47.6	67.4	82.5
2	1/16	54.7	77.4	94.8
1 3/4	3/32	46.8	66.2	81.1
2	3/32	53.8	76.1	93.2

This chart may be used for any steel strut whose $\frac{L}{\rho}$ is greater than that given below

Specification	C=1	C=2	C=3
10225	126	178	218
10227	79.8	113	138

This chart can be used for long Duralumin struts by dividing the value of P from the chart by 3 if $\frac{L}{\rho} > 88.5\sqrt{C}$ = 125 when C=2 and 153 when C=3.

FIG. 5.

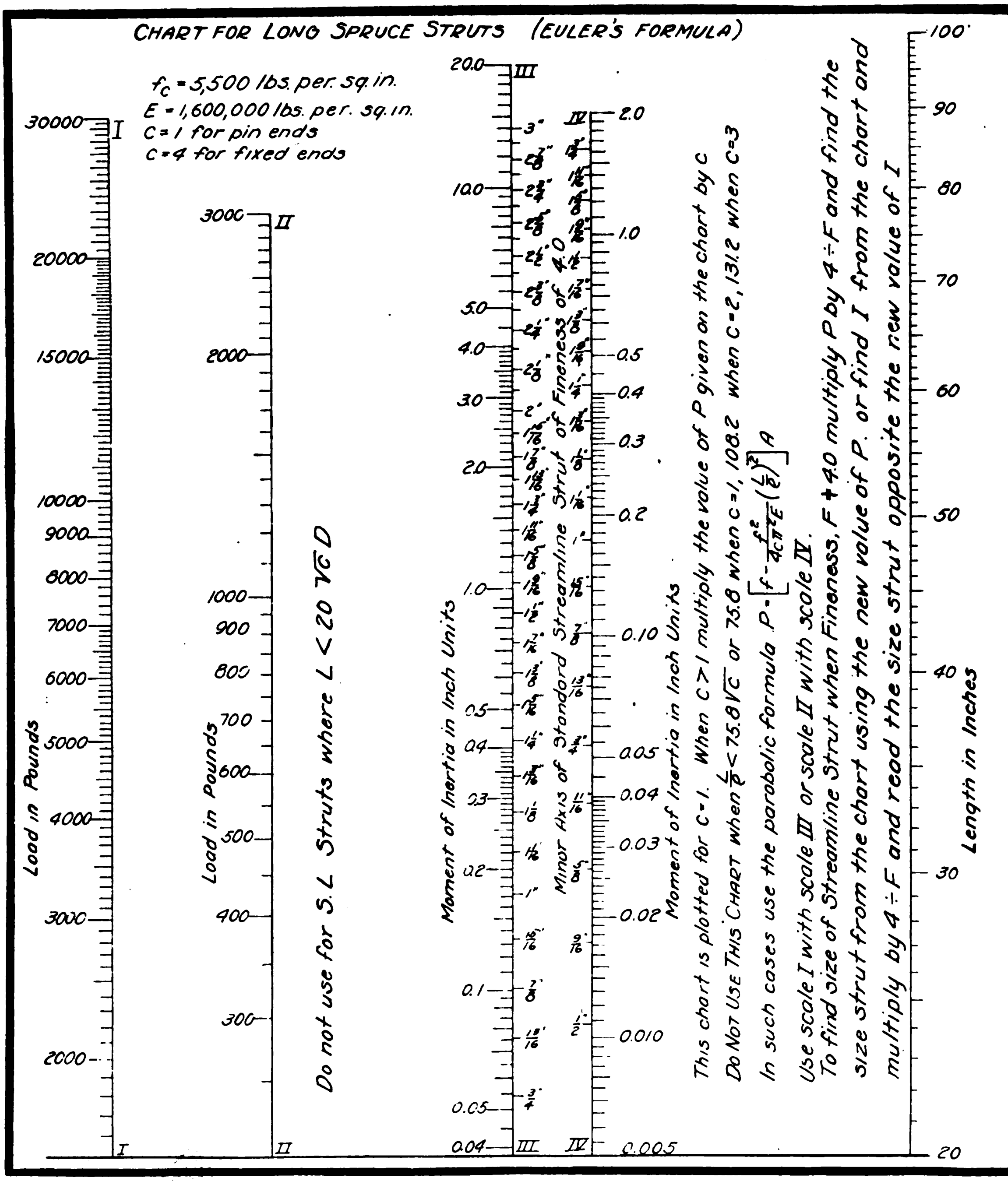


CHART FOR LONG SPRUCE STRUTS (EULER'S FORMULA)
f_c = 5,500 lbs. per sq. in.
E = 1,600,000 lbs. per. sq. in.
C = 1 for pin ends
C = 4 for fixed ends
Load in Pounds
Load in Pounds
Do not use for S.L Struts where L < 20 √C D
Moment of Inertia in Inch Units
Minor Axis of Standard Streamline Strut of Fineness of 4.0
Moment of Inertia in Inch Units
This chart is plotted for C=1. When C>1 multiply the value of P given on the chart by C
Do Not Use This Chart when $\frac{L}{\rho} < 75.8\sqrt{C}$ or 75.8 when C=1, 108.2 when C=2, 131.2 when C=3
In such cases use the parabolic formula $P = \left[f - \frac{f^2}{4C\pi^2 E}\left(\frac{L}{\rho}\right)^2\right]A$
Use scale I with scale III or scale II with scale IV.
To find size of Streamline Strut when Fineness, F ≠ 4.0 multiply P by 4 ÷ F and find the size strut from the chart using the new value of P, or find I from the chart and multiply by 4 ÷ F and read the size strut opposite the new value of I
Length in Inches

FIG. 6.

[redacted] USE ONLY

File D 52.1/Orenco/9 — *McCOOK FIELD REPORT, SERIAL No. 1707*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV — February 15, 1922 — No. 306

PERFORMANCE TEST OF PRODUCTION ORENCO "D" BUILT BY THE CURTISS AEROPLANE & MOTOR CORPORATION EQUIPPED WITH WRIGHT 300 H. P. ENGINE

(PERFORMANCE TEST REPORT No. 68)

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio

August 26, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

PERFORMANCE TEST OF PRODUCTION ORENCO "D" BUILT BY THE CURTISS AEROPLANE & MOTOR CORPORATION, EQUIPPED WITH WRIGHT 300-HORSEPOWER ENGINE.

OFFICIAL PERFORMANCE TEST—SUMMARY OF RESULTS.

AUGUST 26, 1921.

Airplane: Orenco "D".
No.: P-163.
Type: I.
Engine: Wright 300-horsepower.
Propeller: X-1439.
Equipped as: ———.
Weight empty (including water): 1,908 pounds.
Armament and equipment: 345 pounds.
Crew: 180 pounds.
Gasoline: 350 pounds.
Oil: 37 pounds.
Weight loaded: 2,820 pounds.
Weight per square foot: 10.8 (261 square feet).
Weight per horsepower: 8.55 (330 horsepower at 1,810 revolutions per minute).
Fineness: 104 Ae—7.4.

Standard altitude in feet.	Climb.				Speed.		
	Time in minutes.	R.P.M.	Rate ft./min.	Flow gal./hr.	M.P.H.	R.P.M.	Flow gal./hr.
0	....	1,520	1,140	....	139.5	1,810	....
6,500	6.9	1,515	770	....	136.5	1,760	....
10,000	12.1	1,510	575	....	133.5	1,720	....
15,000	24.0	1,505	295	....	125	1,655	....
20,000	....	....	....	....	....	....	....
25,000	....	....	....	....	....	....	....
[1] 18,450	43.0	1,495	100	....	110.6	1,590	....
[2] 20,250	....	1,490	0	....	90	1,490	....

[1] Service ceiling. [2] Absolute ceiling.

Endurance, full throttle: one-half hour at ground and $2\frac{1}{2}$ hours at 15,000 feet.
Minimum speed at sea level (lowest throttle): 64.5 miles per hour.
Landing speed: ———.

PILOT'S OBSERVATIONS.

This pursuit airplane is easy to fly and very steady for an airplane of this type. With full military load it has a marked tendency to porpoise in taking off. The airplane maneuvers well, but is slightly heavy on the controls, especially on the ailerons, and is very tail heavy in a maximum climb up to 15,000 feet. It is easy to land, and has no tendency to turn on the ground, but rolls a good distance.

The cockpit is very roomy and comfortable, with plenty of leg room, and the visibility is good, especially above. The instruments are well placed and easy to read, with the exception of the tachometer, which is placed on the right side of the fuselage and low down. The pilot must place his head inside and bend over to read it.

The vibration of the engine at cruising speeds is very noticeable, and the veneer on the sides of the fuselage vibrates, especially in the bay where the pilot sits. This is the longest bay.

No change in alignment had to be made after the fittings were bedded, and the accessibility to the engine is better than in the original design. Considerable trouble was experienced with the long-tail skid breaking, but shortening the tail skid remedied this, and also slowed up the landing speed, due to the better landing angle obtained.

LOUIS G. MEISTER,
Test Pilot.

DESCRIPTION OF AIRPLANE.

DIMENSIONS.

Overall span: 32 feet $11\frac{5}{8}$ inches.
Overall length: 21 feet $5\frac{1}{2}$ inches.
Overall height: 8 feet $4\frac{1}{4}$ inches.
Height at hub of propeller above ground: ———.
In flying position: 5 feet 1 inch.
At rest: 5 feet 8 inches.

AIRPLANES.

Wing curve: N. A. F., 15; N. P. L., ordinates.
Sweepback: None.
Dihedral, degrees: None.
Stagger: 0 feet 7 inches.
Total area, including ailerons: 272.94 square feet.
Gap: 4 feet $4\frac{13}{16}$ inches.

UPPER PLANE.

[Including center section.]

Span: 32 feet $11\frac{5}{8}$ inches.
Chord: 5 feet.
Area, with ailerons: 150.82 square feet.
Incidence, degrees U: 1° 30′; L: 1° 45′.

LOWER PLANE.

Span: 28 feet.
Chord: 5 feet.
Area: 122.12 square feet.
Incidence, degrees: 1° 30′.

AILERONS OR FLAPS.

Number: 2.
Arrangement: On upper wing.
Upper length: 8 feet $11\frac{13}{16}$ inches.
Upper chord: ———.
Upper area: Each 10.36 square feet.
Lower length: ———.
Lower chord: ———
Lower area: ———.
Total area: 20.72 square feet.
Distance from center of ailerons to longitudinal axis of airplane: 11 feet $11\frac{11}{32}$ inches.

CENTER SECTION.

Area: 10.34 square feet.
Dimensions: 30 inches by 57¼ inches.
Contents: Gravity tank.

STABILIZER.

Area: 14.18 square feet.
Setting: ———.

ELEVATOR.

Area: 14.28 square feet.
Distance from leading edge of elevator to center of gravity of airplane: 14 feet 5¼ inches.

RUDDER.

Area: 7.9 square feet.
Distance from leading edge of rudder to center of gravity of airplane: 12 feet 11½ inches.

FUSELAGE.

Maximum cross section shape: Rectangle rounded top.
Maximum cross section area: 942 square inches.
Maximum cross section dimension: 28¼ by 33 5/16 inches.
Distance of maximum section from leading edge, lower plane: 5 feet 9¾ inches.

LANDING GEAR.

Number of wheels: 2.
Tread: 4 feet 10⅞ inches.
Shock absorbing system: Rubber cord.
Braking device: Tail skid.
Wheels ahead of center of gravity: 23.1 inches.

FIN.

Area: 5.51 square feet.

DISTRIBUTION OF WEIGHTS.

[By pounds.]

Weight empty (with water)	1,908
Armament and equipment	345
Crew	180
Gasoline	350
Oil	37
Weight loaded	2,820
Weight on front wheels (tail skid on ground)	2,336
Weight on tail skid (tail skid on ground)	484
Weight on front wheels (flying position)	2,459
Weight on tail skid (flying position)	371
Center of gravity (distance from wheels in flying position) ... inches	23.9
Center line of axle to point of support of tail skid	15 feet 2 inches

Provisions for special equipment not carried during test.

DESCRIPTION OF POWER PLANT.

ENGINE.

Make: Wright H.
Factory No.: ———.
A. S. No.: 13812.
Type: Vee-8 cylinder.
Number in Plane: 1.
Location: Nose of fuselage.
Rated horsepower: 330.
Rated revolutions per minute: 1,810.
Bore: 5.511 inches.
Stroke: 5.905 inches.
Compression ratio: 5.32 to 1.
Weight dry: 632 pounds.
Gas consumption: 0.521 pound per horsepower hour.
Oil consumption: 0.055 pound per horsepower hour.
Weight of water in engine: 57.9 pounds.

IGNITION.

Battery or magneto: Magneto.
Make: Dixie model 800.
Number: 2.
Advance, degrees: 25°.
Gas interrupter: 0.020 inch.
Distributor: Carbon brush contact.
Plugs, make: Inside vee: A. C.; outside vee: Mosler.
Type: A. C. metal body porcelain insulator; Mosler metal body mica insulator.
Gap: 0.020 inch.

CARBURETORS.

Make: Stromberg.
Type: NA-D6.
Number: 1.
Setting jet: 32
Choke: 1 5/16 inches.
Compensator: None.
Gas drains: One into air intake vertical.
Air intake: Vertical.
Mixture control: ———.
Effect to altitude: 18,000 feet.

RADIATORS.

Make: Curtiss.
Type: A. S. Standard 5-inch core; drawing M. 1317.
Number: 1.
Position: Nose of fuselage.
Frontal area core: 3.45 square feet.
Depth: 5 inches.
Length: 36 inches overall.
Width: 28½ inches overall.
Radiator surface: 170 square feet.

Temperature adjustment: Shutters.
Water capacity: 7.29 gallons.
Flow, gallons per minute: 34.3.
Thermometers, make: Boyce distance reading.
Weight, pounds: 76.5.
Type: Core made of round tubes with hexagonal ends.
Water capacity of whole system: 15 gallons, approximately.

EXHAUST PIPES.

Description: Short individual stacks to each cylinder.

LUBRICATION.

Capacity oil tank: 5.8 U. S. gallons.
Dimensions oil tank: 30 by 17 by 2¾ inches.
Oil used (brand): Liberty.
Oil pressure: 55 to 60 pounds per square inch.
Oil temperature: 60°.
Type pump: Gear.
Wet or dry sump: Dry sump.
Description lubrication system: Gear driven pump forces oil to main bearings and camshaft bearings, and by spray to cylinder walls.

FUEL SYSTEM.

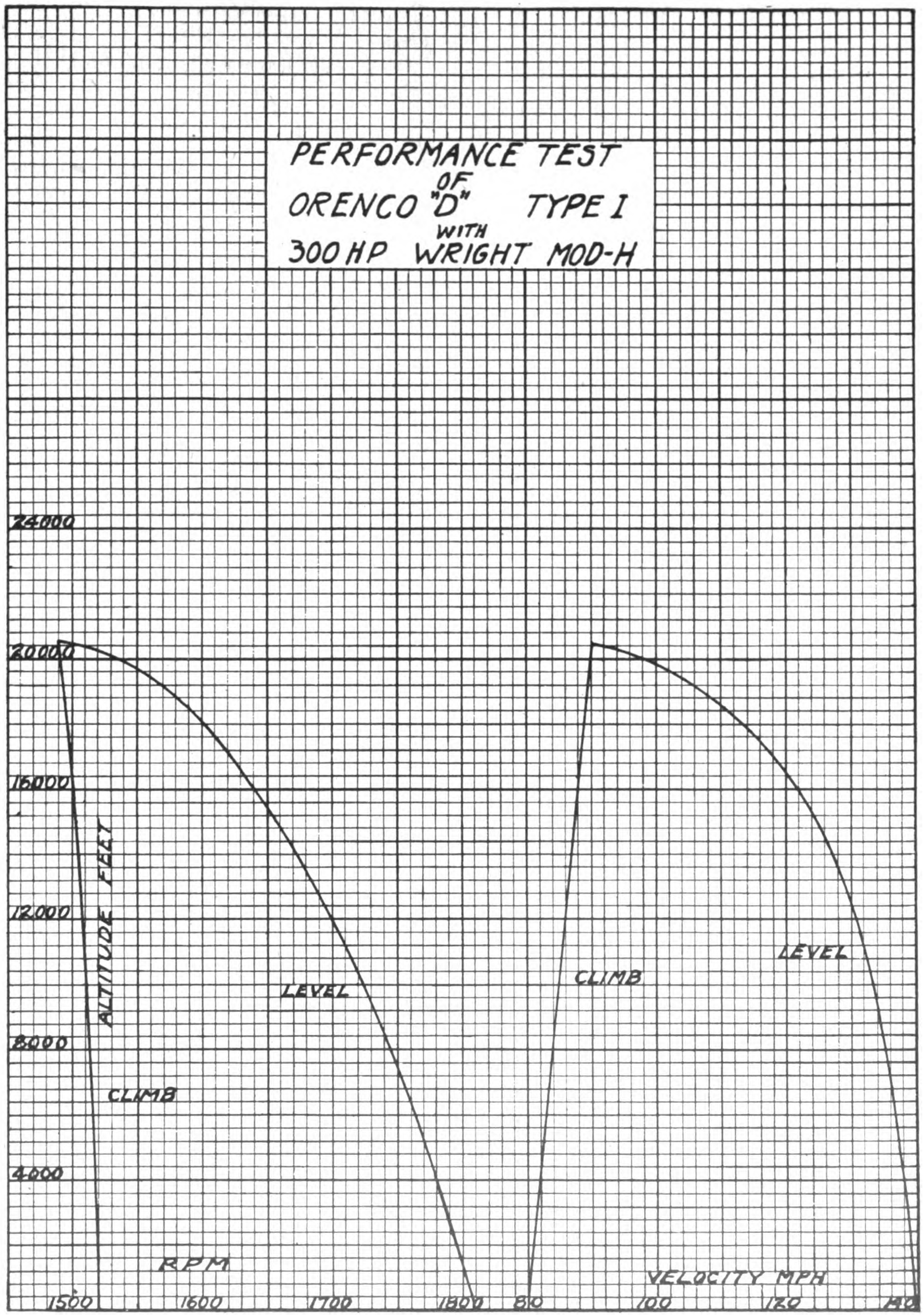
Number of tanks: 2.
Location: Main, between pilot and engine; gravity, center section upper wing.
Capacity, main, pounds: 45 gallons or 270 pounds.
Capacity, reserve: 6 gallons or 36 pounds.
Material: Terne plate.
Description of fuel supply system: Sylphon pump from main tank to gravity tank, by gravity to carburetor.

ENGINE CONTROL.

Description: Throttle lever and switch.

PROPELLER.

Make: Engineering division.
Number of blades: 2.
Diameter: 8 feet 6 inches.
Pitch: 7.10.
Tips: Terne plate.
Clearance: 10 inches.
Manufacturing number: ———.
A. S. No.: 109607.
Remarks: X-14319, 01401.



PERFORMANCE TEST
OF
ORENCO "D" TYPE I
WITH
300 HP WRIGHT MOD-H
24000
20000
16000
12000
8000
4000
ALTITUDE FEET
CLIMB
LEVEL
CLIMB
LEVEL
RPM
1500
1600
1700
1800
VELOCITY MPH
80
100
120
140

FIG. 1.

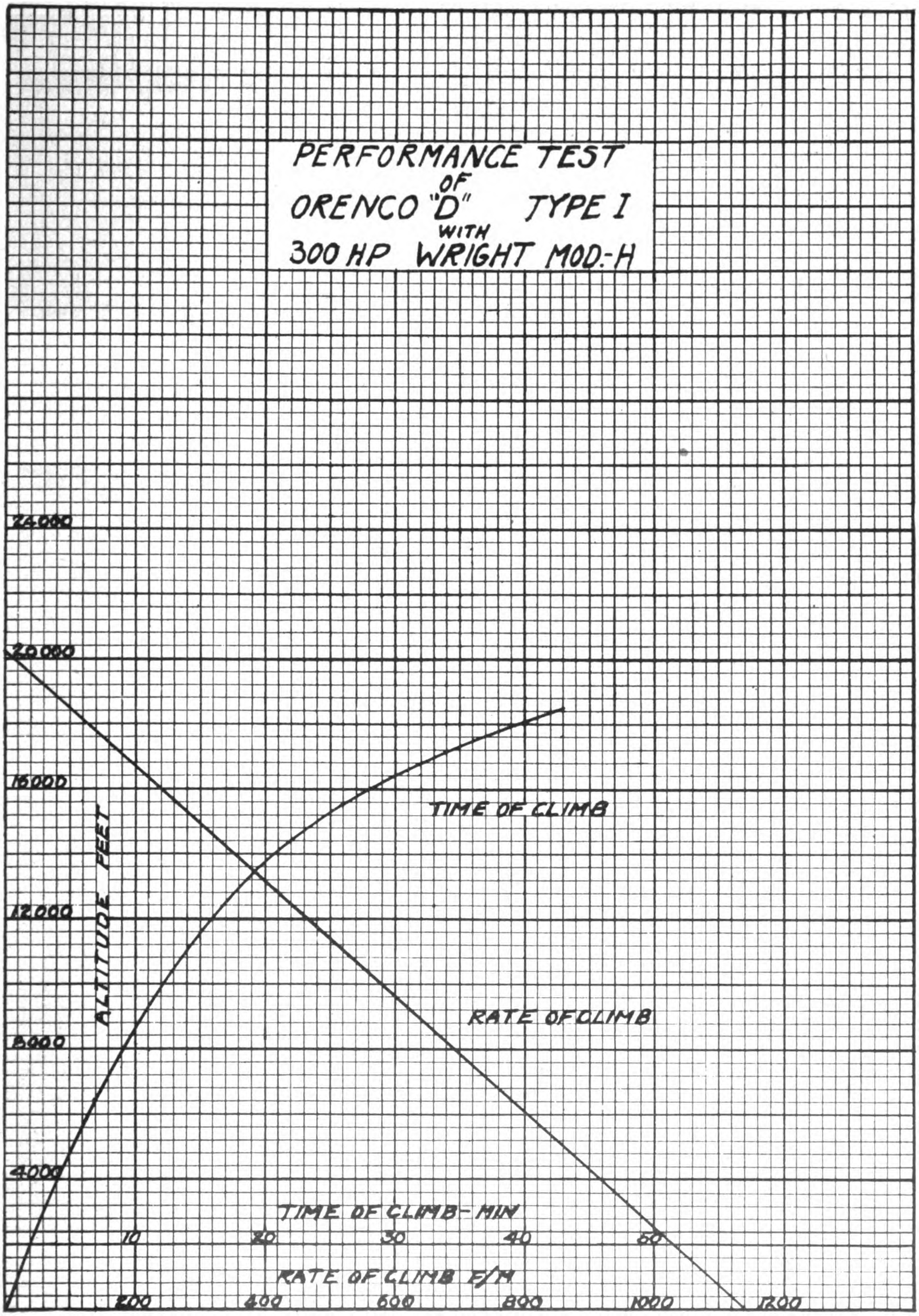

PERFORMANCE TEST
OF
ORENCO "D" TYPE I
WITH
300 HP WRIGHT MOD:-H
24000
20000
16000
12000
8000
4000
ALTITUDE FEET
TIME OF CLIMB
RATE OF CLIMB
TIME OF CLIMB - MIN
10
20
30
40
50
RATE OF CLIMB F/M
200
400
600
800
1000
1200

FIG. 2.

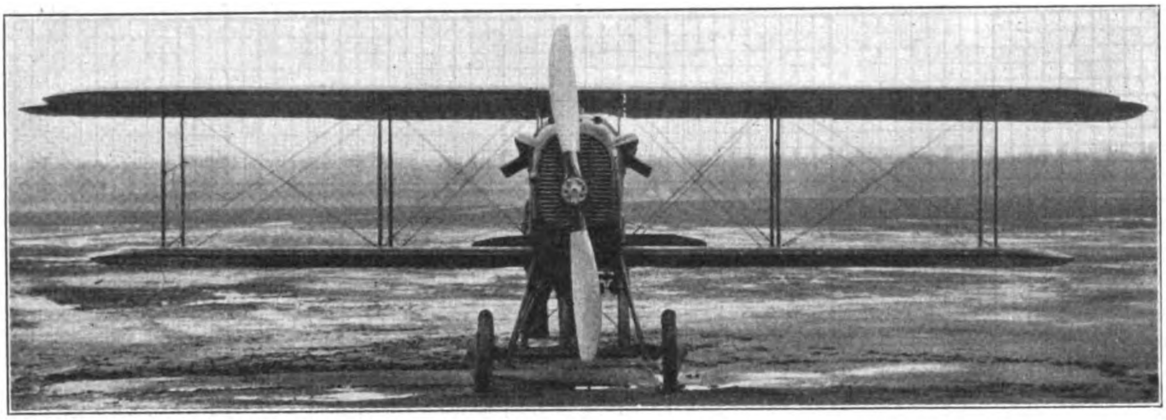


Fig. 3.—Front view.

Fig. 4.—Three-quarter front view.

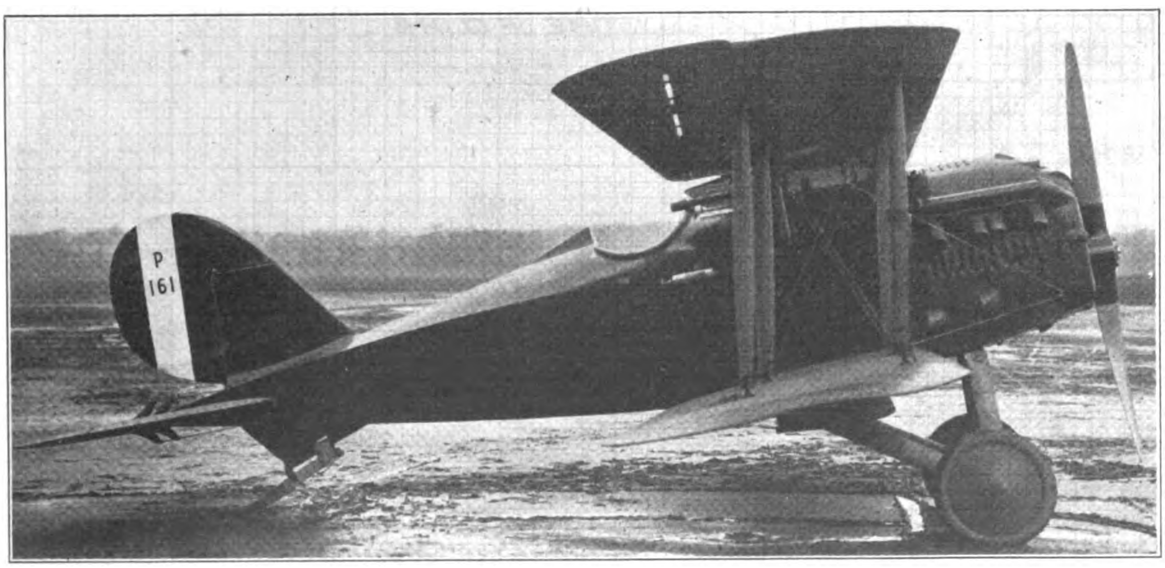


Fig. 5.—Side view.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV February 15, 1922 No. 307

COMPARATIVE STUDY OF TYPE I AIRPLANES WITH VARIOUS POWER PLANTS

(AIRPLANE SECTION REPORT)

7

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
September 15, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.

By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

COMPARATIVE STUDY OF TYPE I AIRPLANES WITH VARIOUS POWER PLANTS.

The purpose of this report is to determine the relative advantages of three types of engines for single-seater pursuit airplanes from the standpoint of weight and size. The engines chosen were the high-compression Wright "H," the high-compression Liberty "12," and the large Packard "12." As the weight of the complete power plant and the disposable load forms such a large proportion of the total weight of an airplane of this type, it is possible to get an accurate comparison between the gross weights of airplanes equipped with different engines. If the type of construction is the same in each case, and if the same materials are used, the structure will in each instance form the same percentage of the total weight, provided the factors of safety are the same for each design.

The fuel and oil required to give the required duration of one-half hour at the ground and two and a half hours at 15,000 feet were computed from a standard table prepared by the power-plant laboratory. The fuel tank and radiator weights were calculated in detail and on the same basis for the three designs.

In computing the dimensions of the wing cellules with the different designs the wings were assumed to be geometrically similar except that the fuselage width was taken constant at 30 inches. Two per cent in each case was allowed for wing cut-outs.

The conclusion to be drawn from Table 2 is that the use of the Packard 2025 in a pursuit airplane would not only result in a much larger, heavier, and less maneuverable airplane but would actually give a higher power loading than the designs with the smaller engines. Until lighter high-power engines are developed the high-compression Liberty "12" is the largest engine that can compete with engines similar to the Wright "H" or Wright radial. Until the excessive vibration of the high compression Wright is overcome it will not be entirely satisfactory. Up to the present time this engine has apparently a smaller power drop off than the high-compression Liberty "12," but the effect of the improved altitude control on the Liberty "12," which has not been tried out as yet, may cause it to be fully as efficient at high altitudes as the Wright engine. If this can be accomplished, the high-compression Liberty would be without doubt the best engine for pursuit airplanes.

TABLE 1.

	Wright HC "H."	Liberty HC-"12."	Packard 2025.
Engine	627	856.6	1,142
Engine water	58	45	58
Propeller	38	44	55
Engine manifolds	15	22	28
Main fuel tank	79	86	103
Gravity fuel tank	48	48	56
Gas piping	18	22	25
Oil tank	16	18.5	24
Oil piping	4	5	6
Water and piping	12	15	20
Expansion tank and water	18	19	20
Radiator and water	115	184	255
Engine controls	8	8	10
Radiator shutters	15	20	25
Total	1,071	1,393	1,832

TABLE 2.—*Comparative weights and dimensions of Type I airplanes.*

	Wright HC "H."	Liberty HC-"12."	Packard 2025.
Power plant	1,071	1,393	1,832
Fuel	384	420	568
Oil	54	63	87
Crew	180	180	180
Armament	215	215	215
Equipment	130	130	130
Gross weight minus structure	2,034	2,401	3,012
Structure, assumed to be 25 per cent of gross weight	676	799	1,008
Gross weight (pounds)	2,710	3,200	4,020
Wing area at 9 pounds per square foot	301	356	447
Span as biplane with aspect ratio of 5.5 (feet)	29.7	32.2	36.0
Chord (inches)	64.7	70.2	78.5
Normal power in flight	360-2,000	450-1,700	540-1,800
Pounds per horsepower based on normal power in flight	7.52	7.11	7.45
Power from laboratory test curves	377-2,000	472-1,700	560-1,800

File D 52.416/9 McCOOK FIELD REPORT, SERIAL No. 1715

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 308

INVESTIGATION OF THE EFFECT OF DOPED FUELS ON FUEL SYSTEM

(MATERIAL SECTION REPORT No. 152)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
September 14, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INVESTIGATION OF THE EFFECT OF DOPED FUELS ON FUEL SYSTEM.

GENERAL.

The use of antiknock compounds in aircraft operation has practically become an absolute necessity for two main reasons, the constantly increasing use of higher compression ratios and the necessity for use of a cheaper fuel. This, the addition of antiknock compounds makes possible.

Accompanying the experimental use of a high test aviation gasoline containing antiknock, occurred the obstruction of the respective gasoline systems by considerable amounts of extraneous matter. It was found that the corrosion of the gasoline tanks and the subsequent accumulation in tubes and strainers of the corroded matter caused the obstructions of the lines. The belief arose that antiknock accelerated this action. It was considered advisable to investigate the effect of fuels and doped fuels on various materials in order to determine if these compounds would produce any injurious results on the fuel system.

PURPOSE.

The purpose of this investigation was to determine the effect of airplane fuels, dopes, and doped fuels on the fuel system, with particular attention to the problem of corrosion prevention.

CONCLUSIONS.

It is found:

1. That the following metals are very slightly, if at all, affected by doped fuels:
   (*a*) Aluminum.
   (*b*) Zinc.
2. That the following materials are very badly affected by such fuels:
   (*a*) Copper.
   (*b*) Brass.
   (*c*) Terneplate.
   (*d*) Iron.
3. That tin plate is moderately affected by these fuels.

It is to be expected, therefore, that considerable difficulty will be experienced with terneplate gasoline tanks and copper lines, brass jets, liners, etc., and to a less extent tin-plated tanks. Caution should be exercised in the use of each of these.

Reasoning by analogy, it is seen that alloys containing magnesium, cobalt, nickel, tungsten, copper, iron, and lead are apt to be very seriously affected by these fuels, while alloys containing aluminum, copper, zinc, and silicon (and in rare cases silver and platinum, as well as osmium and iridium) are apt to be quite resistant to these fuels.

MATERIALS.

The materials used in this investigation are determined by the nature of the materials used in a typical fuel system (see fig. 1). These materials are largely aluminum, copper, brass, steel, terneplate, and tin plate. Zinc plate was included for the purpose of finding out how it stood up in comparison with the above. All of these materials were obtained in sheet form from stock at McCook Field, with the exception of the zinc plate, which was prepared in the chemical laboratory of the Material Section.

Rubber hose of the following description was included in this investigation:

Goodyear gasoline, line, $\frac{5}{16}$ inch inside diameter.

Cloth wrapped gasoline line, $\frac{3}{8}$ inch inside diameter.

Unarmored pump hose, $\frac{3}{4}$ inch diameter.

This material was likewise obtained from stock at McCook Field.

The action of the following fuels on the above materials was investigated:

(*a*) High test gasoline.

(*b*) Low test gasoline.

(*c*) Antiknock compound.

(*d*) 91 per cent high test gasoline containing 9 per cent antiknock.

(*e*) 97 per cent high test gasoline containing 3 per cent antiknock.

(*f*) 50 per cent high test gasoline, 50 per cent benzol.

(*g*) 84 per cent low test gasoline, 16 per cent antiknock.

The high test gasoline, low test gasoline, and benzol were obtained from stock at McCook Field. The antiknock compound is Antiknock No. 1. It was obtained from the General Motors Corporation, Research Division, Moraine City. It is claimed that this antiknock compound is composed of 70 per cent aromatic amines and 30 per cent benzol. The amines are probably orthotoluidine, paratoluidine, xylidine, aniline, or mixture of these.

A complete chemical analysis (page 4) was made on all metal stock used, and distillation curves (see fig. 8) were run on fuels. These data are included for purpose of reference.

METHOD OF PROCEDURE.

In the case of the metals, the sheet stock was cut into small strips 4 inches long and 1 inch wide. These were placed in the above fuels and doped fuels in such a manner that only half of the specimen was covered with the liquid. The other half was thereby exposed to atmosphere saturated with the vapors of each fuel. Two series were run in parallel; one series was placed in flasks which were securely stoppered so as to exclude all possibility of ventilation and entrance of moisture and, therefore, represented the conditions present in a gasoline tank which was partially filled with liquid and the rest of the tank filled with practically moisture-free air, saturated with the fumes of the fuel in the tank. The other series was run under identical conditions, with the exception that all flasks were allowed to remain unstoppered and were placed in a large container, which was sealed to prevent entrance or exit of fumes. This container was saturated with moisture vapor, thereby reproducing the conditions that are present in a partially filled gasoline tank

when the atmosphere is very high in moisture content. It was believed that this latter condition would impose a much more rigorous test on the materials than the above practically moisture-free series. This was found to be the case.

The rubber gasoline lines were tested from specimens made by cutting the hose into sections 6 inches in length, stoppering one end with a cork stopper and inserting in the other end a 6-inch glass tube. The gasoline hose and affected. The exposure extended over a period of 145 days.

DISCUSSION OF RESULTS.

It is observed that the metal which stood up better than any other examined is aluminum. Second to this is zinc, and third in order is tin, while steel, terneplate, and particularly copper and the copper alloy, brass, are very badly affected by fuels containing antiknock compounds.

DIAGRAM OF TYPICAL FUEL SYSTEM.

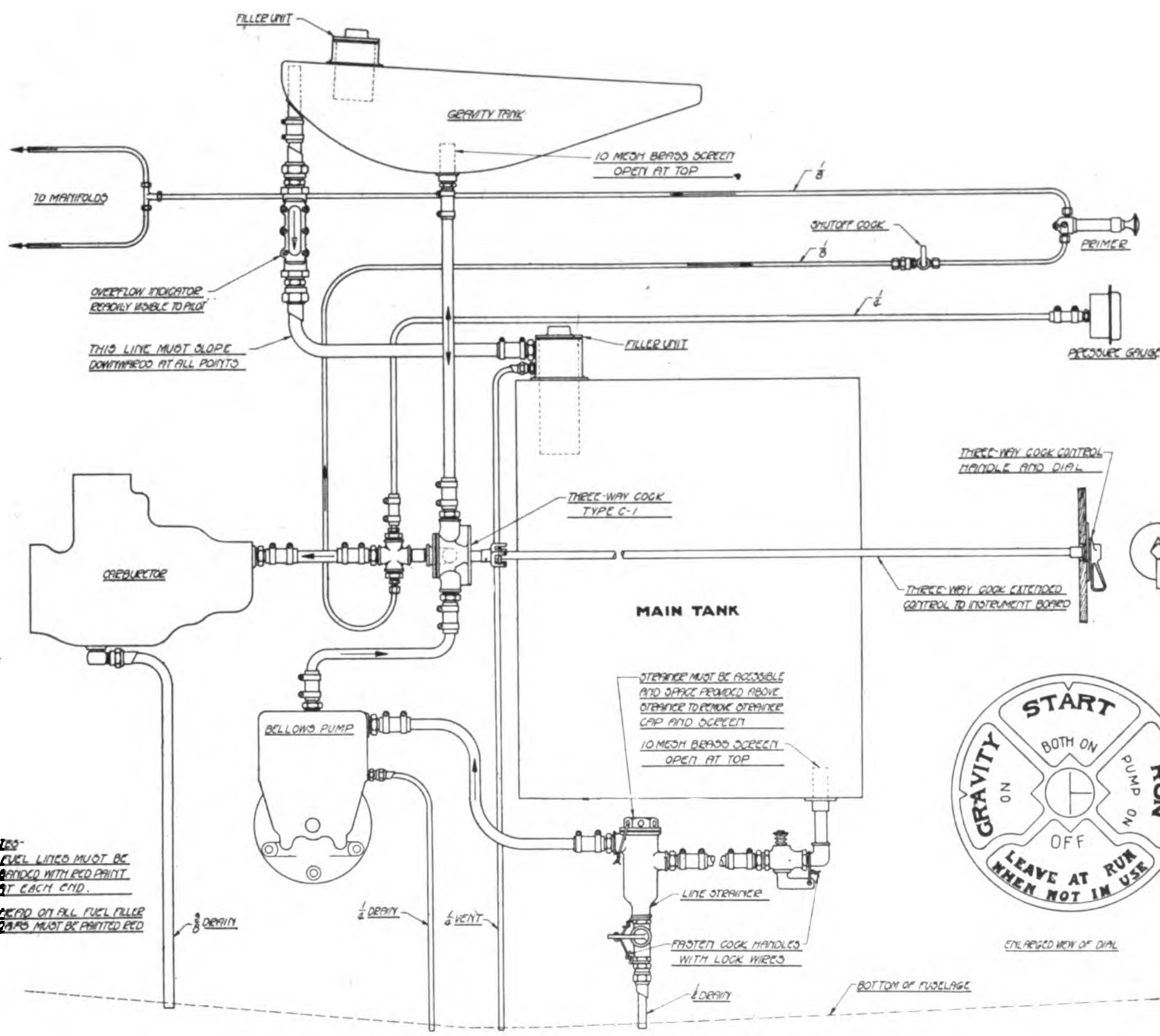


FIG. 1.—Materials used in fuel system.

glass tube were then filled with the fuel and securely stoppered. The fuels in these tubes evaporated within a few days. The tubes were refilled and allowed to evaporate a second time. They were left undisturbed until the time of examination at the conclusion of the test.

RESULTS.

The results obtained in this investigation are charted in schematic form in figures 5 and 6. These data were obtained by noting the effect of the various fuels and doped fuels on the materials, and stating the results in the form of slightly or somewhat affected, badly affected, and un-

The deleterious action of these compounds on the metals present in the fuel system is considerably increased by the presence of moisture. Figure 2 shows the results of the action of fuels and doped fuels on the various metals in the absence of moisture. Figure 3 shows the action of these fuels in the presence of moisture. Figure 4 presents the metals in their original condition before the tests were begun. It will be noted that the metals in figures 1 and 2, which have been affected by the various compounds, are considerably darker than the originals shown. The actual corrosion which took place is very difficult to show by means of photograph. However, some idea of the relative

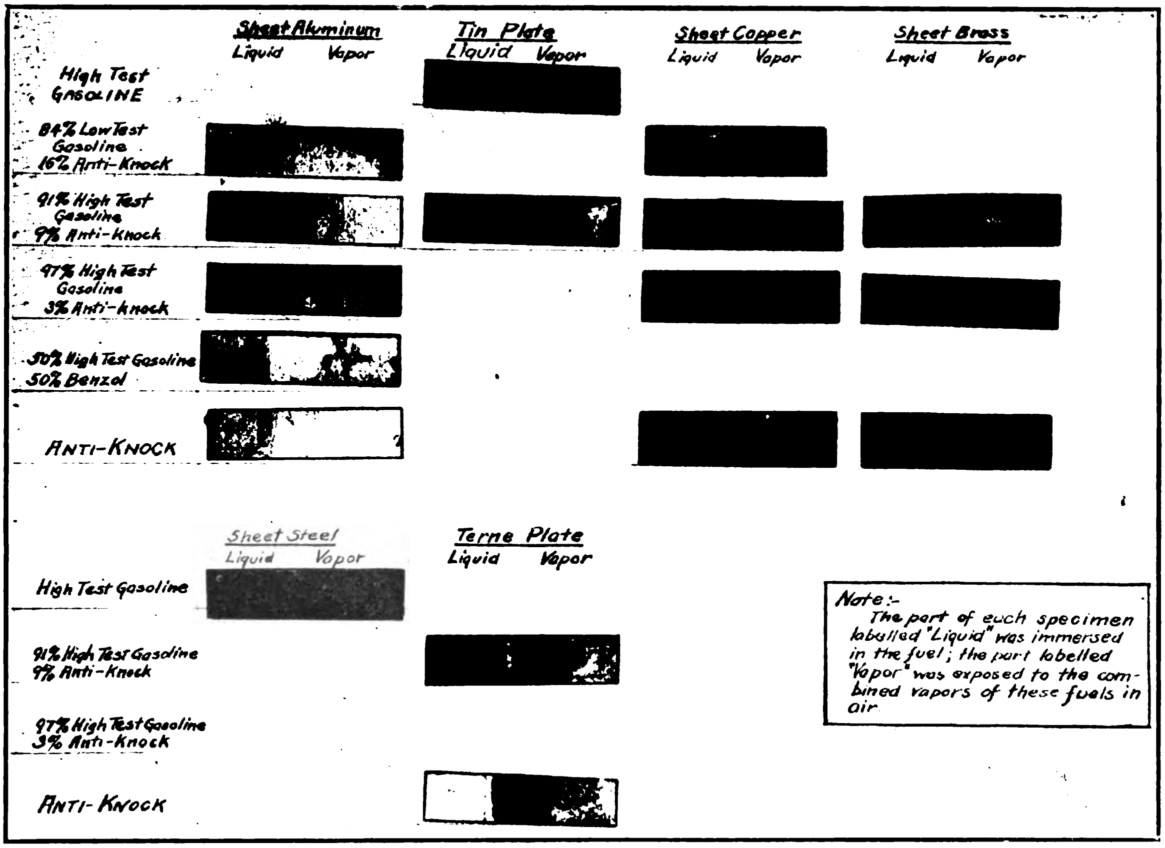


FIG. 2.—Condition of material after 145 days' exposure.

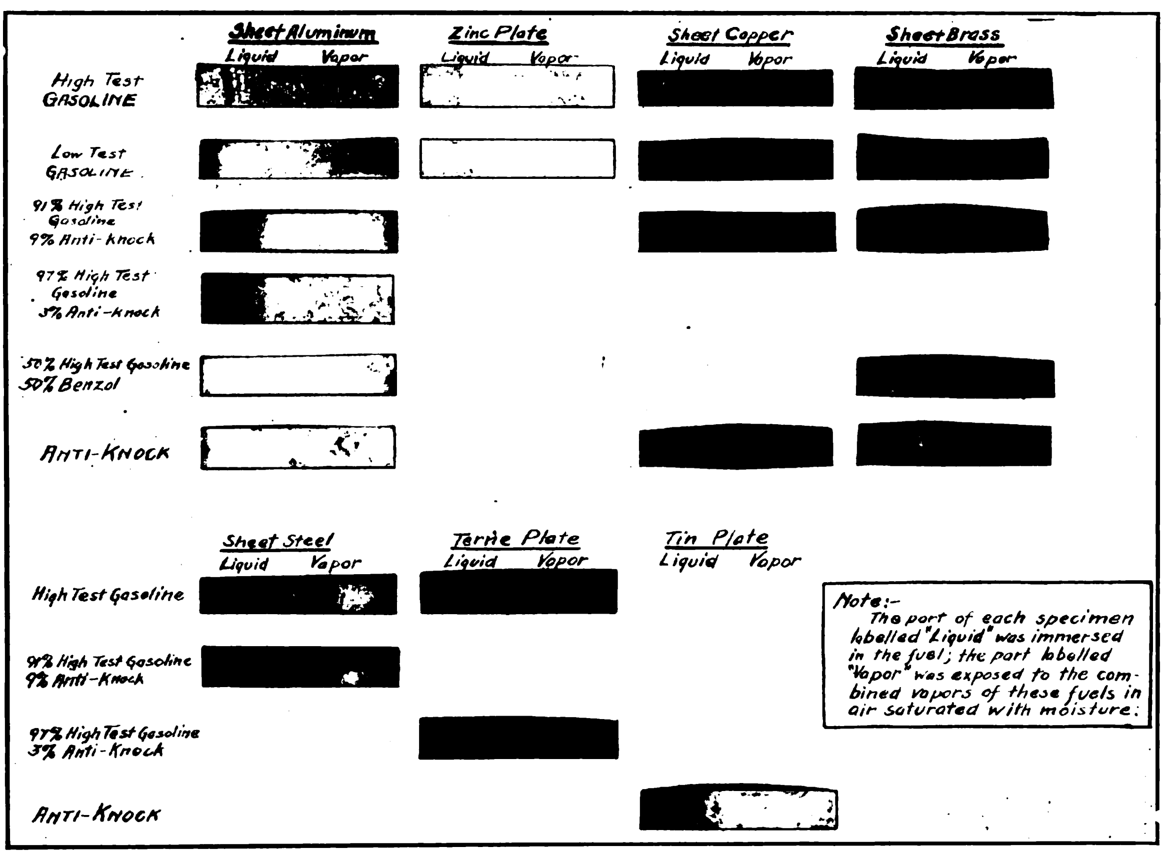


FIG. 3.—Condition of material after 145 days' exposure (moisture series.)

effects can be obtained by comparing the varying degrees of darkness of the samples as compared with their originals. It will be noted that the darkest samples, that is those that were most affected, are copper and brass. This "effect" was in the form of a combined corrosion of the metal and a deposition from the fuel, the total deposit being in the form of a tacky residue.

It is, therefore, to be expected that these compounds will affect, to a considerable extent, copper tubes, terneplate gasoline tanks, brass or bronze couplings, while aluminum housings, aluminum pumps, etc., will probably suffer only slightly, if at all.

Tin plate (dairy stock) can be expected to hold up much better than terneplate, and it is, therefore, a natural conclusion that dairy stock should be used for gasoline tanks in preference to terneplate.

The ideal material for gasoline tanks appears to be aluminum, for not only has aluminum withstood the tests of this investigation better than any of the other metals, but it has also been found that aluminum is the least

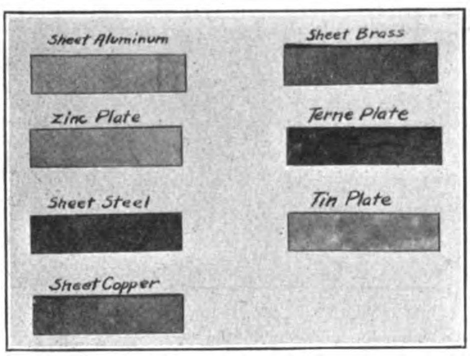


FIG. 4.—Original condition of material.

affected by sulphur and other compounds extracted by gasoline from rubber gasoline lines. (See Naval Aircraft Factory report on "Effect of corrosive material in rubber hose upon gasoline tanks") and that aluminum gasoline tanks suffer least from corrosion (see report "Tests on fuel tanks for aircraft," Naval Aircraft Factory). The corrosive action of doped fuels will be particularly marked if these fuels are allowed to remain for some length of time in the fuel system.

Reasoning by analogy, the results obtained from certain other metals and alloys of various metals can be anticipated after the manner outlined in figure 5. Figure 5 gives a graphical representation of the effect of antiknock compound on various metals, arranged in descending order of magnitude, that is, the metals at the top of the curve are probably the least affected, while those at the bottom of the curve are most affected, and those in between these two components are affected in the order of magnitude relative to their position.

It is, therefore, to be expected that alloys containing rather high percentages of aluminum, zinc, and in some rare cases, silver and platinum, will not be affected by antiknock compound, while alloys containing magnesium, copper, cobalt, nickel, and tungsten will be very greatly affected by such compounds, and alloys containing chromium, manganese, tin, and lead moderately affected. That is to say, it is to be expected that such materials, as for example the B. G. spark plug, containing largely nickel with a trace of manganese, and the B. G. Ferronica spark plug, containing chromuim, nickel, and iron, will both suffer considerable fouling from these fuels. It is possible, however, that the high heat of the cylinder may prevent this. Other materials containing such elements are certain to cause trouble if placed in the gasoline system.

In the case of rubber lines, it is believed that difficulty may be expected only in those cases where high percentages of antiknock compounds are used. It is to be expected that in such cases a thick gummy substance will accumulate in the lines and possibly in the tanks. This of course is prohibitive. The rubber lines subjected to the action of fuels containing small percentages of antiknock compounds seem to have suffered insufficient deterioration to warrant their consideration.

EFFECT OF FUELS AND DOPED FUELS ON RUBBER.

Goodyear Gasoline Line, 5/16-inch inside diameter.—No apparent effect of the above fuels on this line except that a heavy tacky deposit is formed when high percentages of antiknock are used.

Cloth wrapped gasoline line, 3/8-inch inside diameter.—Slight discoloration by all fuels and also some deposit. Antiknock produced a heavy tacky deposit.

Unarmored pump hose, 3/4-inch diameter.—No apparent effect produced by high-test gasoline, low-test gasoline, and benzol. Each fuel, using antiknock, discolored the inside of the hose and left more or less of a tacky deposit.

Straight antiknock produced the same deposit to a greater extent.

CHEMICAL ANALYSIS OF SHEET STOCK.

Tinned sheet steel, Specification No. 10207A: 5 pounds per base box of 112 sheets, 14 by 20 inches.

Terne sheet steel, Specification No. 10209A: 8 pounds per base box of 112 sheets, 28 by 20 inches:

Tin	per cent..	20.0
Lead	do....	80.0

Sheet copper, 99.9 per cent copper.

Sheet aluminum:

Silicon	per cent..	0.08
Copper	do....	4.00
Iron	do....	0.62
Aluminum	do....	95.30

Sheet brass:

Lead		Trace.
Copper	per cent..	79.77
Iron	do....	0.21
Zinc	do....	20.02

Sheet steel, 0.023 ga., Specification No. 10201:

No. 1020 steel:

Carbon	per cent..	0.15–0.25
Do	do....	0.20–0.30
Manganese	do....	0.30–0.60
Do	do....	0.50–0.80
Phosphorus	do....	0.045
Maximum	do....	0.045
Sulfur	do....	0.050
Maximum	do....	0.050

Galvanized sheet steel, 0.001 inch thick:

Zinc	per cent..	99.9

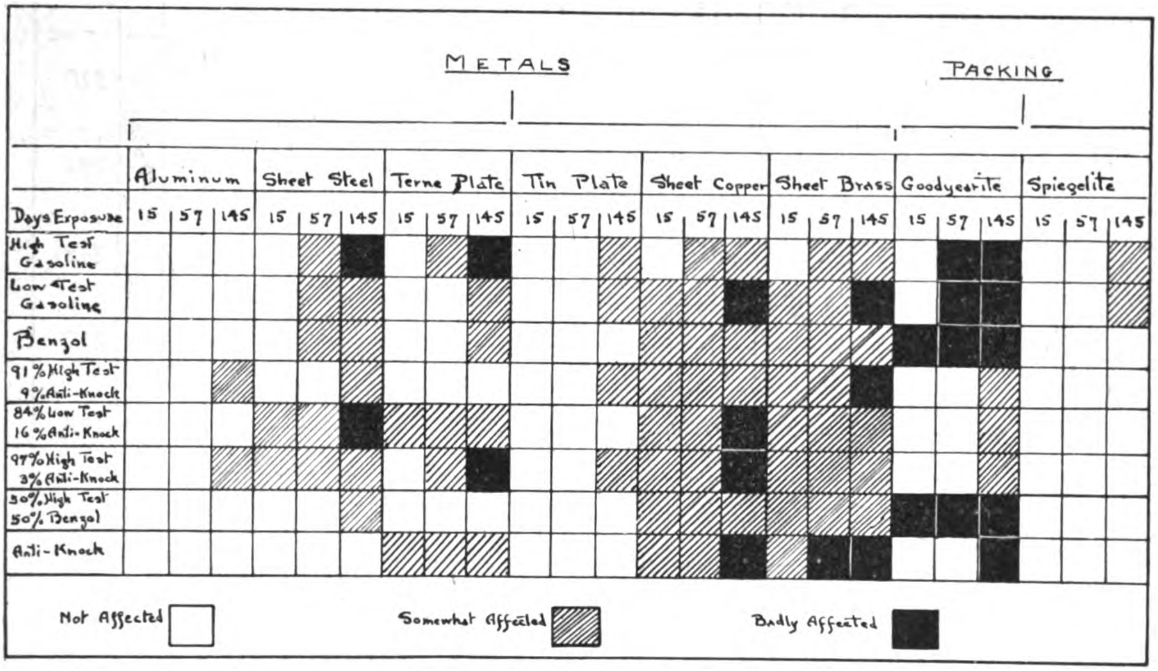


FIG. 5.—The effect of fuels on fuel systems in the absence of moisture.

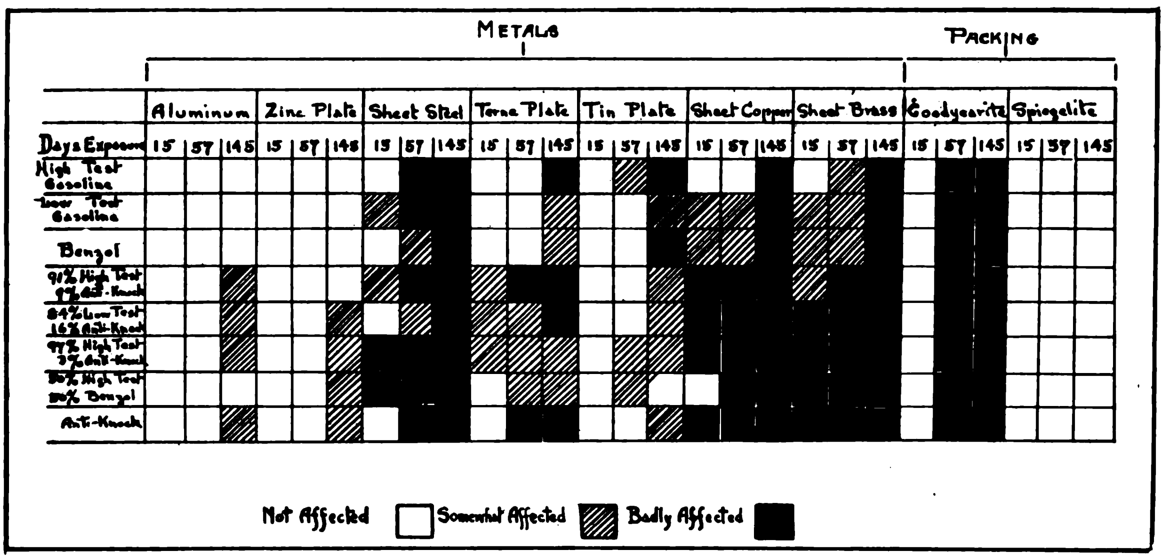


FIG. 6.—The effect of fuels on fuel systems in the presence of moisture.

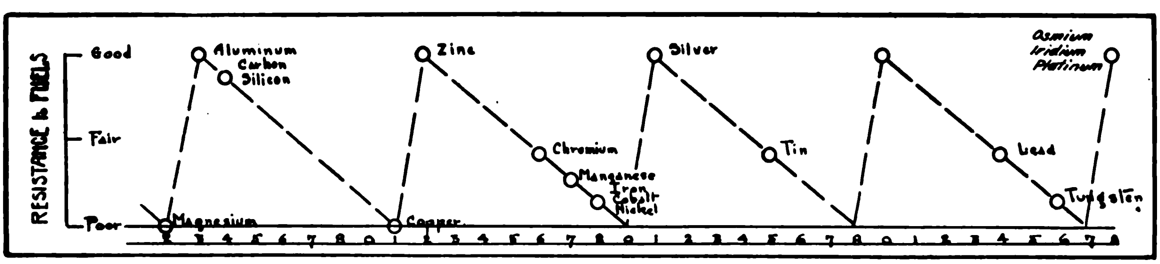


FIG. 7.

NOTE—From the above chart it is possible to predict the effect of doped fuels on various metals. The points aluminum, copper, zinc, tin, iron, and lead have been experimentally determined.

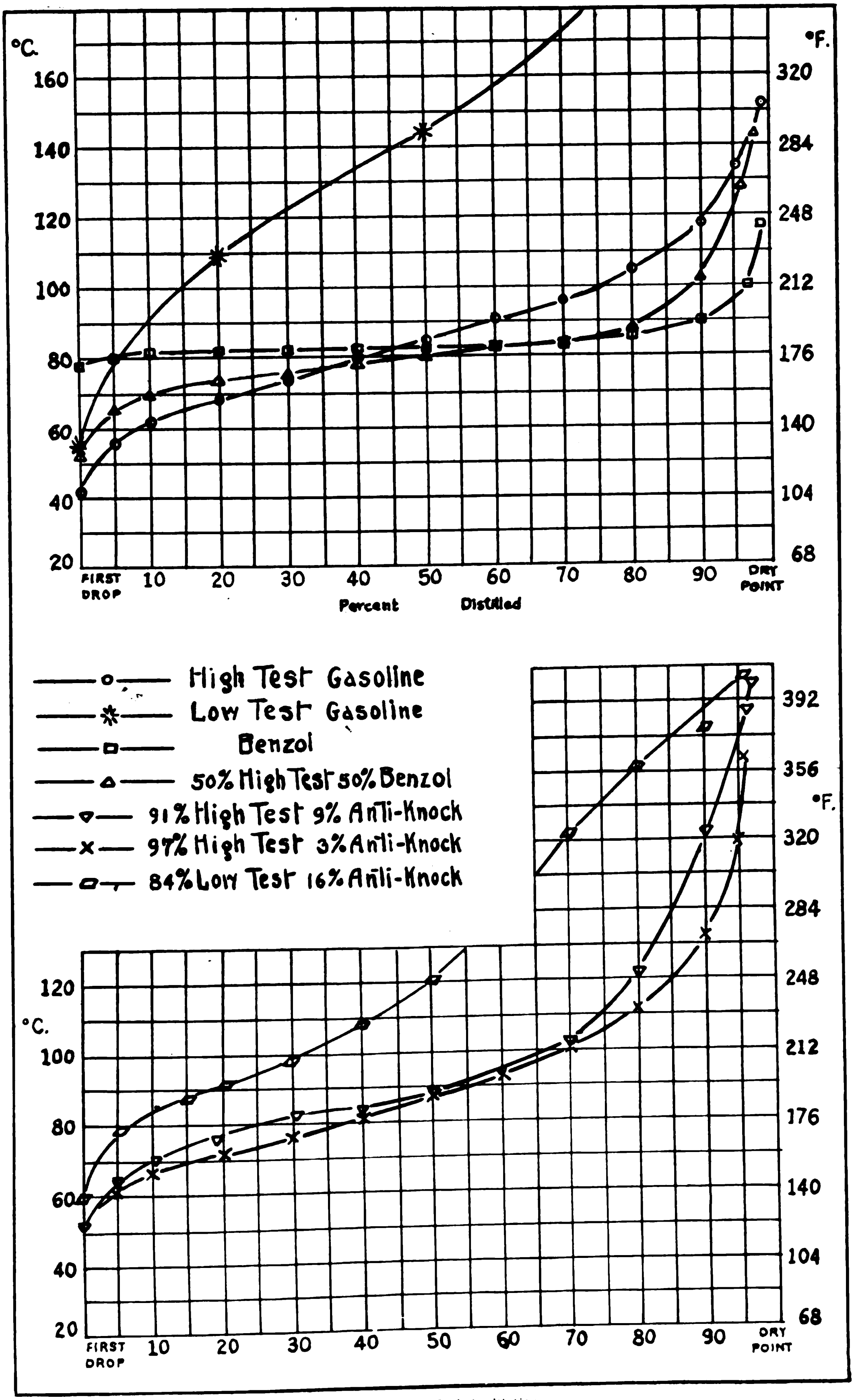


FIG. 8.—Motor fuel distillation.

FOR OFFICIAL USE ONLY
File D 52.41/Hispano-Suiza/102

McCOOK FIELD REPORT, SERIAL No. 1717

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 309

TEST TO IMPROVE FUEL CONSUMPTION CHARACTERISTICS OF THE STROMBERG TYPE NA-D6 CARBURETOR ON THE 300 H. P. HISPANO-SUIZA ENGINE

(POWER PLANT SECTION REPORT)

7

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 31, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

TEST TO IMPROVE FUEL CONSUMPTION CHARACTERISTICS OF THE STROMBERG TYPE NA-D6 CARBURETOR ON THE 300 H. P. HISPANO-SUIZA ENGINE.

OBJECT OF TEST.

The object of this test was to improve the fuel consumption characteristics of the type NA-D6 Stromberg carburetor on the 300-horsepower Hispano-Suiza engine, especially at part throttle positions.

SUMMARY OF RESULTS.

A new type of accelerating well was devised which, with a slight change in the carburetor, reduces the fuel consumption materially, at the same time retaining all accelerating qualities.

CONCLUSIONS.

It is recommended that this modified type of well and setting be adopted as standard for all NA-D6 carburetors.

INTRODUCTION AND DESCRIPTION.

As will be noted from the fuel consumption curve in Figure 2, the fuel consumption of the Hispano-Suiza 300-horsepower engine with the NA-D6 type of carburetor is excessive, especially at part throttle, with the mixture control in the full rich position.

The high specific fuel consumption at full throttle is caused by the large size of fuel metering orifice necessary for satisfactory acceleration of the engine. The rapid rise of the specific fuel consumption curve as the engine is throttled on propeller load is a characteristic of the double venturi construction. This inherent enrichment of the mixture by the double venturi is made more pronounced in the NA-D6 carburetor by the use of an air bleed accelerating well.

It is obvious from these curves that if the accelerating qualities could be retained the fuel consumption could be reduced considerably both at full and part throttle without reaching mixtures so lean as to cause bad engine operation.

The Stromberg NA-D6 carburetor (see Figure 4) is of the air bleed, double venturi type, and the principles of operation are the same as all Stromberg carburetors. The fuel reaches the engine by passing from the float chamber through a metering orifice and accelerating well to a discharge nozzle from which it is drawn into the passing air stream. The idling is accomplished by means of separate idling tubes which are connected to the outside of the accelerating wells at the bottom and which pass up the back of the barrels of the carburetor, the fuel entering the main passages at the points where the butterfly throttles touch the walls in closing. The accelerating well (see Figure 5) contains small holes which serve a triple purpose. The primary purpose of these holes is to allow fuel to enter from the outside of the accelerating well when the throttle is opened rapidly, thus giving a richer mixture for acceleration. At full throttle operation these holes act as air bleeds allowing air, which is taken from behind the venturis and passes down the side of the idling tube, to enter the main discharge. These holes also serve to feed the idling well and consequently furnish the fuel for idling speeds. The standard setting for this carburetor is as follows: Large venturi—$1\frac{13}{16}$-inch; size of metering orifice—No. 32 drill size, accelerating well as shown in Figure 5.

METHOD OF TESTING.

This test was made using NA-D6 carburetors applied to Hispano-Suiza 300-horsepower engines mounted on both the dynamometer and torque stand and finally tested in flight. For the method of making runs and taking readings see Engineering Division Report, Serial No. 1507. Full power and propeller load runs on the dynamometer were made with every variation of carburetor setting tried, and the changes giving the most favorable results were tried for acceleration on the torque stand.

In all a total of 108 runs were made throughout the test. The trials for acceleration were made on the torque stand with the engine equipped with a propeller. Throughout the test the fuel consumption was kept within the desired limits by changing the fuel metering orifice size.

The test can be divided into three phases. At first it was decided to try to obtain a decrease in the fuel consumption without altering the main carburetor body but only the accelerating well and this by changing the location, size, or number of the air-bleed holes. In this way it was hoped to flatten the specific fuel consumption curve on propeller load. The air-bleed holes were systematically shifted from the bottom to the top of the accelerating well by stages and runs made for each location and size. Also the idle was both eliminated and fed directly from the float chamber. The results of these tests showed that the smaller the number of air-bleed holes, and the closer these holes were to the top of the well, the flatter the propeller load specific fuel consumption curve obtained and the better the fuel consumptions at throttled loads. From these results an accelerating well was made which materially reduced the specific fuel consumption on propeller load. However, when tried out on the torque stand the engine acceleration with this well in the carburetor was not good and the well could not, therefore, be recommended for service use.

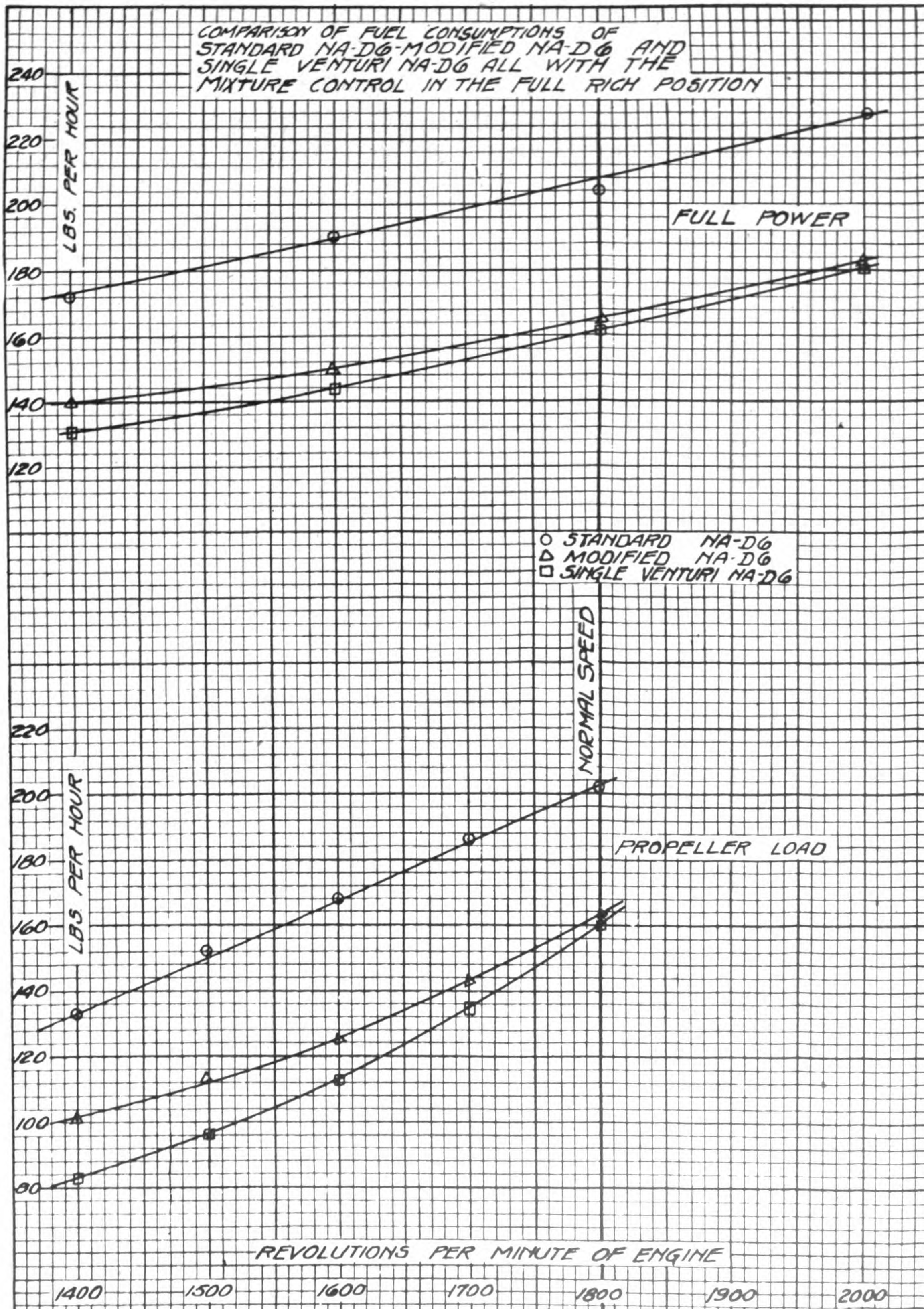

COMPARISON OF FUEL CONSUMPTIONS OF STANDARD NA-D6-MODIFIED NA-D6 AND SINGLE VENTURI NA-D6 ALL WITH THE MIXTURE CONTROL IN THE FULL RICH POSITION
LBS. PER HOUR
FULL POWER
○ STANDARD NA-D6
△ MODIFIED NA-D6
□ SINGLE VENTURI NA-D6
NORMAL SPEED
PROPELLER LOAD
LBS PER HOUR
REVOLUTIONS PER MINUTE OF ENGINE
240
220
200
180
160
140
120
100
80
1400
1500
1600
1700
1800
1900
2000

FIG. 1.

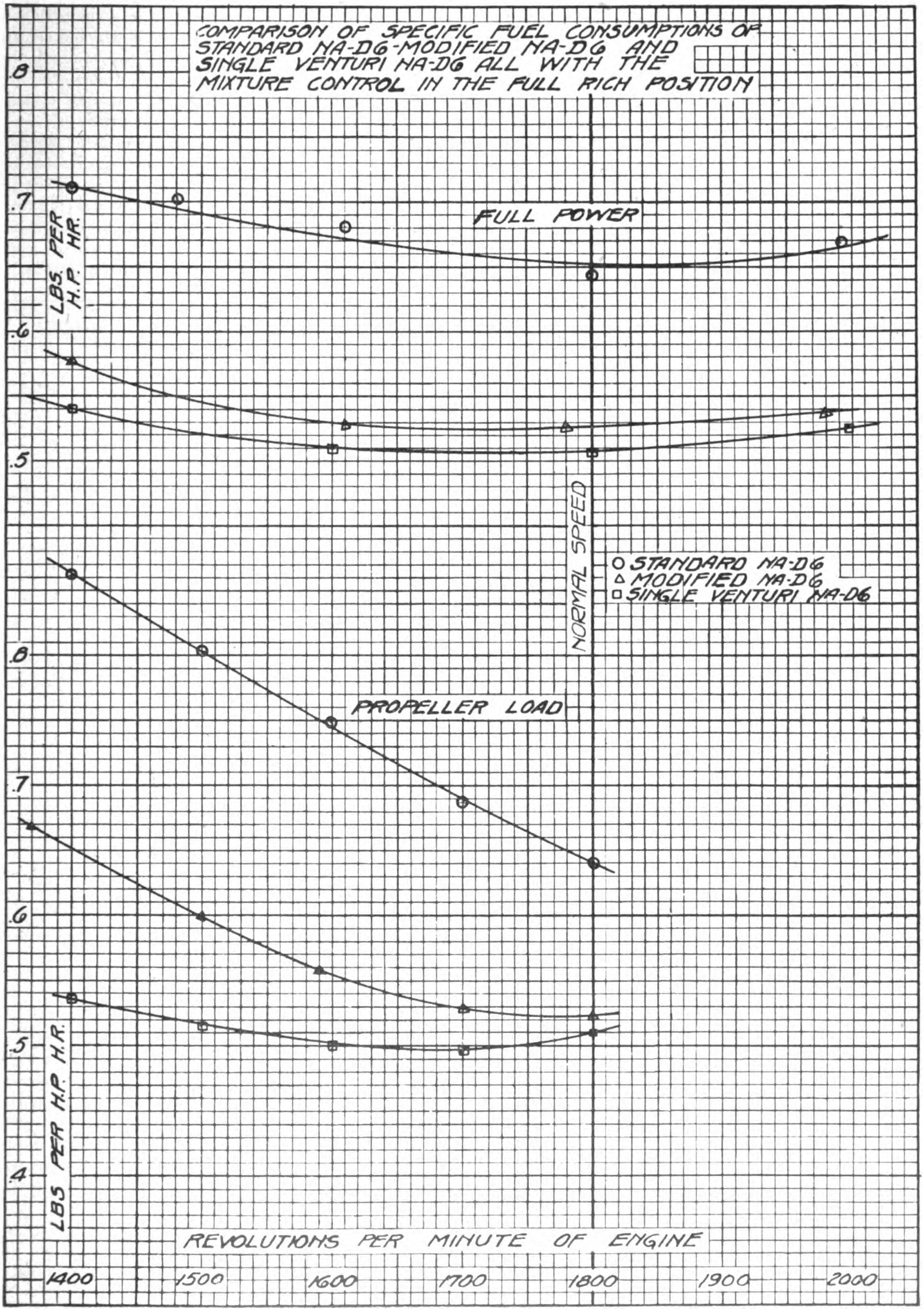

COMPARISON OF SPECIFIC FUEL CONSUMPTIONS OF STANDARD NA-D6-MODIFIED NA-D6 AND SINGLE VENTURI NA-D6 ALL WITH THE MIXTURE CONTROL IN THE FULL RICH POSITION
FULL POWER
LBS. PER H.P. HR.
NORMAL SPEED
○ STANDARD NA-D6
△ MODIFIED NA-D6
□ SINGLE VENTURI NA-D6
PROPELLER LOAD
LBS PER H.P. H.R.
REVOLUTIONS PER MINUTE OF ENGINE
.8
.7
.6
.5
.8
.7
.6
.5
.4
1400
1500
1600
1700
1800
1900
2000

FIG. 2.

From the results of the first phase it was evident that it was impractical to prevent the enrichment of the mixture on propeller load by changing the air-bleed holes in the accelerating well. It was also evident that one reason why the engine required such a very rich mixture for acceleration was because upon a sudden opening of the throttle the fuel lying around the accelerating well had a great distance to travel before discharging into the main air passage. It was, therefore, decided to reduce the fuel consumption on propeller load by eliminating the auxiliary or small venturi. It was believed that if the accelerating well was raised close to the discharge nozzle, the acceleration with the single venturi would be satisfactory. An arrangement of this kind was constructed (see fig. 6) and the usual runs made. The fuel consumption (see fig. 2) and the acceleration when the carburetor was in a level position were excellent. However, due to the distance from the center of the float to the accelerating well, when the carburetor was tilted, as it would be in flight, the fuel either spilled over the discharge nozzle or the level was below the accelerating well so that the engine would not accelerate. As it was impossible to change the relation of the discharge nozzle to the float chamber, the single venturi type of setting had to be abandoned, since it would not operate in inclined positions.

Since the fuel compensating characteristics could not be improved, it was obvious that the only method left to improve the fuel consumption with the carburetor in its present form was to devise an accelerating well which would improve the accelerating qualities to such an extent that the metering orifice size could be reduced and thus reduce the fuel consumption. After several trials a well of this kind was obtained, a sketch of which is shown in figure 7, and the fuel consumption curve given in figure 2. This well gives good acceleration in all normal flying and ground positions with a No. 35 metering orifice, which materially reduces the fuel consumption.

Fuel consumption curves for the various arrangements tested both for propeller load and full-throttle runs will be found in figure 1 and specific consumption curves in figure 2. These consumptions were all taken with mixture control in the full rich position, and a careful pilot using the mixture control would materially reduce the consumption shown by the curve for the standard setting.

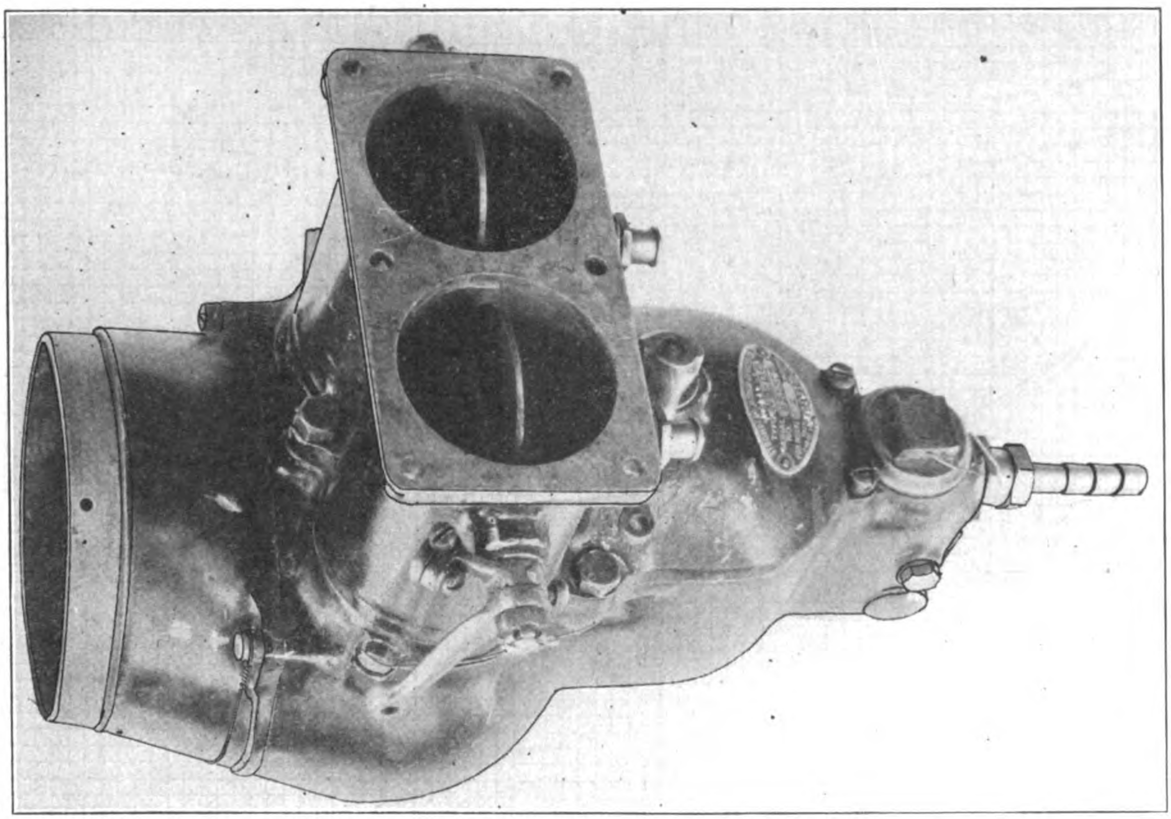


FIG. 3.- View of Stromberg NA-D6 carburetor.

ANALYSIS.

Up to a certain limit, determined by the acceleration, the fuel compensating characteristics of an air-bleed accelerating well can be changed at will by a change in the number, size, or location of the air-bleed holes. With a single venturi, a practically ideal fuel consumption curve can be obtained over the propeller load range by proper sizing of the air-bleed holes. Raising the accelerating well with relation to the discharge nozzle improves the acceleration.

In general, it is evident that the NA-D6 carburetor has some inherent disadvantages such as distance from discharge nozzle to center of float, which can be eliminated only by complete redesign of the carburetor. It is believed that the changes developed by this test allow of

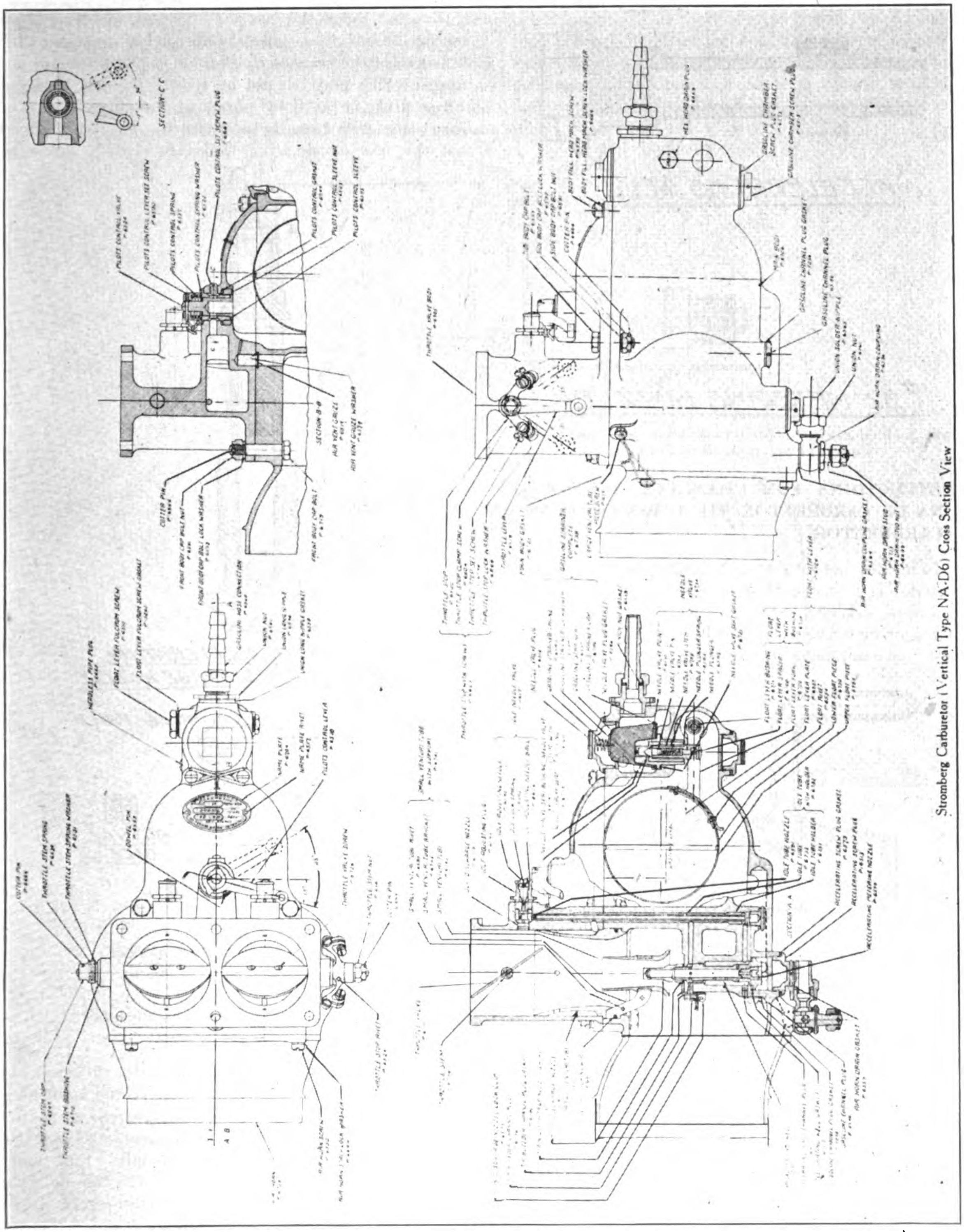


FIG. 4.—Assembly drawing of Stromberg NA-D6 carburetor.

as lean a main-jet setting as is practicable for year-round operation, and as good compensation on propeller load as it is possible to obtain with the present NA-D6 carburetor body.

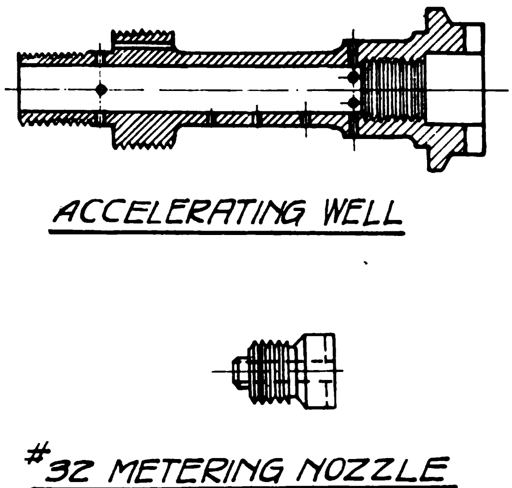


FIG. 5.—Sectional view of old type accelerating well and metering nozzle for NA-D6 Stromberg carburetor.

INSTRUCTIONS FOR CHANGING A STANDARD NA-D6 CARBURETOR TO A MODIFIED NA-D6 CARBURETOR.

To modify one NA-D6 carburetor, the following special material is required: 2 new type accelerating wells, 2 new type discharge nozzles, 2 No. 35 metering orifices, and 2 air metering plugs (see fig. 7). After securing the new type equipment, separate the halves of the carburetor

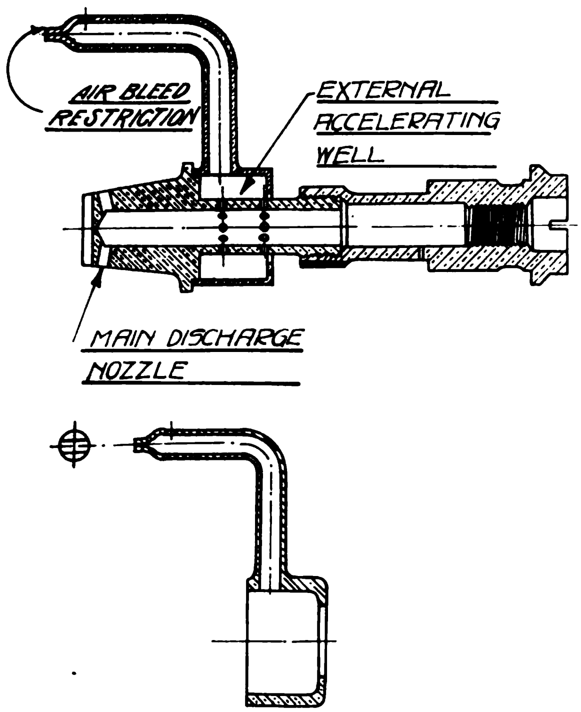


FIG. 6.—Accelerating well and discharge nozzle used with single venturi in NA-D6 Stromberg carburetor.

and remove the venturis and accelerating wells and proceed as follows:

Two air vent holes will be found in the carburetor as at (A) (see fig. 8). Drill and tap these holes for ¼ inch—32 threads. Screw the two small brass air metering plugs (see fig. 7) into these holes. Care should be taken that the edges of the air metering orifice in the plugs are not injured. The plugs should be tightly screwed in place and securely fastened by punching the edges in two or three places with a small center punch. It will be noticed that the new accelerating wells are slightly larger in

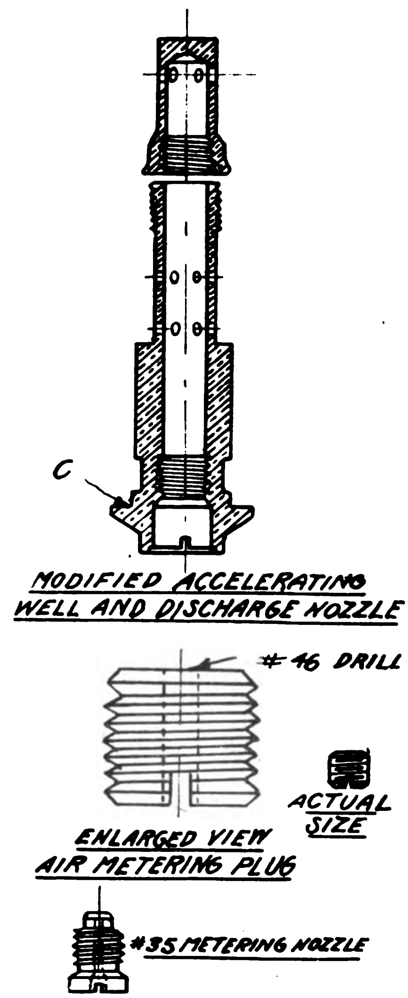


FIG. 7. New type equipment for Stromberg type NA-D6 carburetor.

diameter than those removed. It will, therefore, be necessary to slightly enlarge the holes in the main body of the carburetor at (B). For this purpose a $\frac{7}{16}$-inch drill will be necessary. It is necessary to enlarge the first thin section of material at (B) only. First make sure that the shoulders on the bottom (B) (see fig. 7) of the accelerating wells have a fiber gasket in place. Insert the new accelerating wells in their position in the carburetor and fasten securely by screwing the new type discharge nozzles on the top of the accelerating wells. Securely screw the discharge nozzles in place. These

should be fastened with the old discharge nozzle lock clip. Screw the No. 35 metering jets in their place in the bottom of the accelerating wells, reassemble carburetor and safety wire for service use. Mark the aluminum name plate with the letters MOD ¼ inch high immediately above the letters TYPE NA-D6. The letters should be stamped with steel stamps. It is of the greatest importance that all modified carburetors have this distinctive marking as there is great possibility of confusion since the type of setting can not be determined by external examination. It is recommended that in addition to this marking the bowls or other prominent part of the carburetors be painted with the letters MOD one to two inches high with yellow paint.

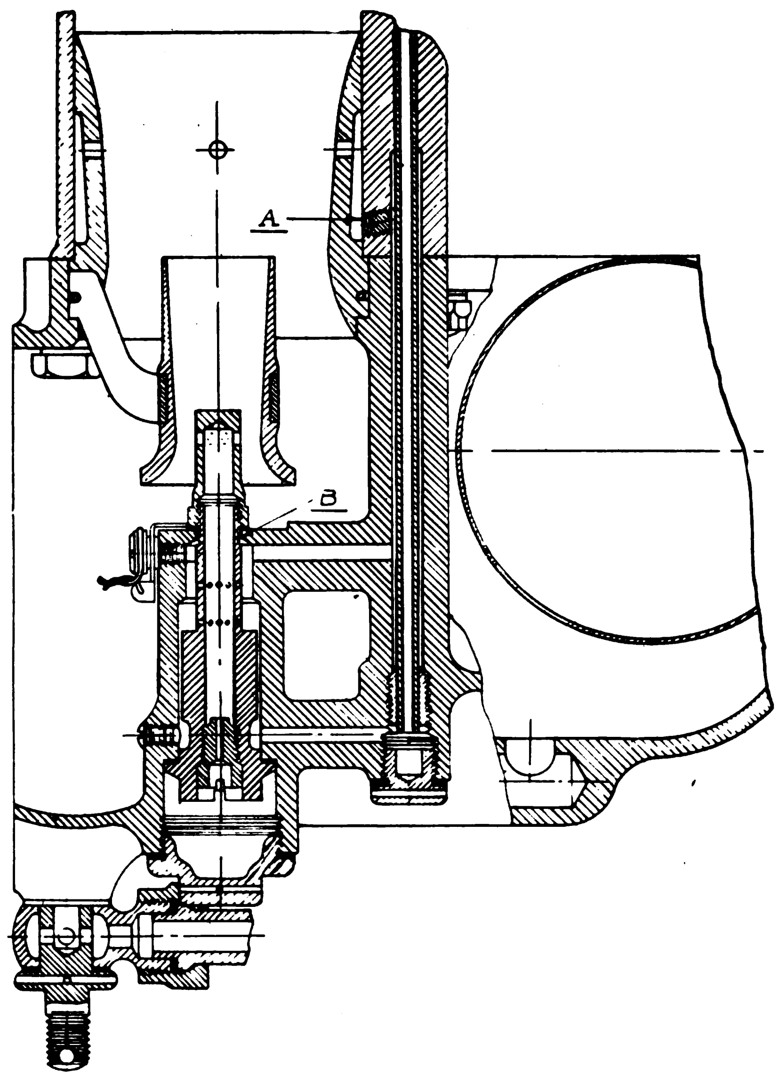


FIG. 8.—Sectional view of modified NA-D6 carburetor showing new wells, jets, discharge nozzles, and air-metering plugs in place.

O

FOR OFFICIAL USE ONLY

File D 52.1 / Fokker / 58

McCOOK FIELD REPORT, SERIAL No. 1721

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 310

PERFORMANCE TEST OF FOKKER D-VII EQUIPPED WITH PACKARD 1237 ENGINE

(PERFORMANCE TEST REPORT No. 69)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio,
August 31, 1921

7

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

PERFORMANCE TEST OF FOKKER D-VII EQUIPPED WITH PACKARD 1237 ENGINE.

OFFICIAL PERFORMANCE TEST—SUMMARY OF RESULTS.

AUGUST 31, 1921.

Airplane: Fokker D-VII.
No.: P-195.
Type: I.
Engine: Packard 1237.
Propeller: 24705.
Equipped: Approximately as *Alert*, allowing for extra gas and oil carried.
Weight empty (including water): 1,867 pounds.
Armament and equipment: 70 pounds.
Crew: 180 pounds.
Gasoline: 308 pounds.
Oil: 37 pounds.
Weight loaded: 2,462 pounds.
Weight per square foot: 10.43 pounds.
Weight per horsepower: 7.04 pounds (350 horsepower at 1,975 revolutions per minute).

Standard altitude in feet.	Climb.				Speed.		
	Time in min.	R. p. m.	Rate ft./min.	Flow gal./hr.	M. p. h.	R. p. m.	Flow gal./hr.
0	....	1,680	1,700	....	151	1,975	....
6,500	4.6	1,645	1,180	....	147	1,905	....
10,000	8.0	1,625	895	....	144.5	1,860	....
15,600	15.5	1,595	490	....	138.5	1,785	....
20,000	37.7	1,455	80	....	116.0	1,655	....
25 000	....	....	....	....	....	....	....
[1] 19,750	34.9	1,555	100	....	121.5	1,670	....
[2] 21,000	....	1,545	0	....	91	1,545	....

[1] Service ceiling. [2] Absolute ceiling.

Endurance, full throttle at 10,000 feet (including climb); 2 hours 13 minutes.

Minimum speed at sea level (lowest throttle), 63 miles per hour.

Landing speed, ———.

PILOT'S OBSERVATIONS ON FOKKER D-VII WITH PACKARD 12 HIGH-COMPRESSION ENGINE.

The flying qualities of the Fokker D-VII equipped with the Packard 12 high-compression engine are of course similar in most respects to airplanes of this type equipped with the standard B. M. W. or Mercedes engines, the most noticeable points of difference being in landing and maneuvering ability.

Due to the increase in weight this airplane lands with considerably more speed than the standard Fokker, and rolls much further after being on the ground. It is not, however, an especially difficult airplane to land.

The airplane is sensitive on the controls, but is stiffer laterally than the standard Fokker. On the whole it does not maneuver as nicely as the B. M. W. engined airplane, due presumably to the distribution of a greater amount of weight over a longer portion of the fuselage, which appears to have a tendency to hold the airplane in its given course, and to resist any turning moment. The airplane can, however, be maneuvered very quickly and nicely by the application of a greater amount of force on the controls than is required on the standard Fokker.

The airplane is quite tail heavy in level flight wide open near the ground. This tendency disappears rapidly above 10,000 feet, and the airplane is perfectly balanced at an altitude of from 18,000 to 20,000 feet.

The nose radiator cools the engine perfectly. It never overheated on the hottest days, and the shutters were generally required above 10,000 to 12,000 feet in the climb, being fully closed above 17,000 feet in both climb and speed courses.

The general arrangement of the cockpit is good, as far as location of instruments, etc., is concerned. The throttle mixture control, shutters, and gas shut-off valve are all operated by levers and rods giving a very smooth, positive action, and delicate adjustment. They are the most satisfactory set of controls for these devices of any airplane I have ever flown. The placing of the seat and rudder bar is bad, however, making a most uncomfortable seating arrangement which practically paralyzes the pilot's legs and body in a flight of two hours. Also the seat is so constructed that it is impossible to use a parachute with it.

During the entire test the Packard engine ran perfectly, giving no trouble whatever, and requiring no adjustments of any kind. This engine runs with an almost entire absence of vibration at any speed up to 2,000 revolutions per minute. It throttles perfectly and runs smoothly, without any roughness or difficulty in carburation, backfire, or spitting at any desired speed. It has a remarkably quick and smooth acceleration and appears never to "load up." It is a very easy engine to start, generally starting the first time over.

On the whole from the pilot's standpoint it is a delightful engine to fly and maintain.

MUIR S. FAIRCHILD,
1st Lieut. A. S., Test Pilot.

DESCRIPTION OF AIRPLANE.

DIMENSIONS.

Overall span, 27 feet 5½ inches.
Overall length, 23 feet.
Overall height, 9 feet 3 inches.
Height at hub of propeller above ground:
In flying position, 5 feet 3 inches.
At rest, 6 feet ¾ inch.

AIRPLANES.

Wing curve, Fokker varying.
Sweepback, none.
Dihedral, degrees, upper, 2°; lower, 1° 20′.
Stagger, 2 feet 1 inch.
Total area including ailerons, 236 square feet.
Gap, ——.
Area of plane between wheels, 11 square feet.

UPPER PLANE.

(Including center section.)

Span, 27 feet 5½ inches.
Chord, 5 feet 3 inches.
Area with ailerons, 145 square feet.
Incidence, degrees, none.

LOWER PLANE.

Span, 22 feet 11¼ inches.
Chord, 3 feet 11¼ inches.
Area, 91 square feet.
Incidence, degrees, 1° to 1.5°.
Gap, 4 feet 6¼ inches.

AILERONS OR FLAPS.

Number, 2.
Arrangement, upper wing only.
Upper length, 7 feet 2½ inches.
Upper chord, 7.5 to 12 inches balanced.
Upper area, 6.62 square feet.
Lower length, ——.
Lower chord, ——.
Lower area, ——.
Total area, 13.24 square feet.
Distance from center of ailerons to longitudinal axis of airplane

CENTER SECTION.

Area, none.
Dimensions, ——.
Contents, ——.

STABILIZER.

Area, 20.4 square feet.
Setting, fixed not adjustable.

ELEVATOR.

Area, 18.4 square feet.
Distance from leading edge of elevator to center of gravity of airplane, 16.04 feet.
Center of gravity, 3.1 inches to rear of leading edge of lower plane.

RUDDER.

Area, 6.8 square feet.
Distance from leading edge of rudder to center of gravity of airplane, 16.09 feet.

FUSELAGE.

Maximum cross-section shape, rectangular.
Maximum cross-section area, 9.35 square feet.
Maximum cross-section dimension, 3 feet 9½ inches by 2 feet 5½ inches.
Distance of maximum section from leading edge, lower plane, 3 inches.

LANDING GEAR.

Number of wheels, 2.
Tread, 71 inches.
Shock-absorbing system, spiral steel spring.
Braking device, tail skid.
Wheels ahead of center of gravity, 14 inches.

FIN.

Area, 2.9 square feet.

DISTRIBUTION OF WEIGHTS.

	Pounds.
Weight empty (with water)	1,867
Armament and equipment	70
Crew	180
Gasoline	308
Oil	37
Weight loaded	2,462
Weight on front wheels (tail skid on ground)	2,218
Weight on tail skid (tail skid on ground)	244
Weight on front wheels (flying position)	2,342
Weight on tail skid (flying position)	120

Center of gravity (distance from wheels in flying position), 9.9 inches.
Center line of wheels to point of support of tail skid, 16 feet.
Provisions for special equipment not carried during test.

DESCRIPTION OF POWER PLANT.

ENGINE.

Make, Packard.
Factory No., 2.
A. S. No., 94602.
Type, Vee. 12-cyl.
Number in plane, 1.
Location, nose of fuselage.
Rated horsepower, 300.
Rated revolutions per minute, 1,800.
Bore, 5-inch.
Stroke, 5½-inch.
Compression ratio, 5.5 to 1.
Weight, dry, 738 pounds.
Gas consumption, 0.515.
Oil consumption, 4.1 pints per brake horsepower hour.
Weight of water in engine, 39 pounds.

IGNITION.

Battery or magneto, magneto.
Make, Berkshire.
Number, 2.
Advance, 27°.
Gas interrupter, 0.020.
Distributor, carbon brush contact.
Plugs, make, A. C.
Type, metal body, porcelain insulator.
Gap, 0.015.

CARBURETORS.

Make, Zenith.
Type, Duplex Packard Zenith, single venturi.
Number, 1.
Setting jet, 165.
Choke, 31 m/m.
Compensator, 170.
Gas drains, 1.
Air intake, led into slipstream below fuselage.
Mixture control, Standard.
Eff. to Altitude, ———.

RADIATORS.

Make, Harrison.
Type, Honeycomb.
Number, 1.
Position, nose of fuselage.
Frontal area, 5.2 square feet.
Core depth, 5 inches.
Length, over all, $42\frac{3}{8}$ inches.
Width, $28\frac{5}{8}$ inches.
Radiator surface, 260 square feet.
Temperature adjustment, shutters.
Water capacity, 65 pounds.
Flow gallons per minute, satisfactory.
Thermometers, make, Boyce, Type C.
Weight, 110 pounds.
Water capacity of whole system, 110 pounds.

EXHAUST PIPES.

Description: Short individual stacks to each cylinder.

LUBRICATION.

Capacity oil tanks, 20 quarts.
Dimensions oil tank, ———.
Oil used (brand), Liberty.
Oil pressure, 60 pounds.
Oil temperature, 120°.
Type pump, gear.
Wet or dry sump, dry sump.
If wet, capacity, ———.
Description lubrication system, standard.

FUEL SYSTEM.

Number of tanks, 1.
Location, between pilot's seat and engine.
Capacity, main, 47.5 gallons.
Capacity, reserve pounds, ———.
Material, ———.
Gauge, ———.
Description of fuel supply system, pressure system; air pump on engine forces gasoline to carburetor.

ENGINE CONTROL.

Description, throttle lever and switch.

PROPELLER.

Make, Engineering Division.
Number blades, 2.
Diameter, 8 feet 8 inches.
Pitch, 6.41 feet.
Tips, terneplate.
Clearance, ———.
Mfg. No., ———.
A. S. No., 108,958.
Remarks, X-24705; 01175.

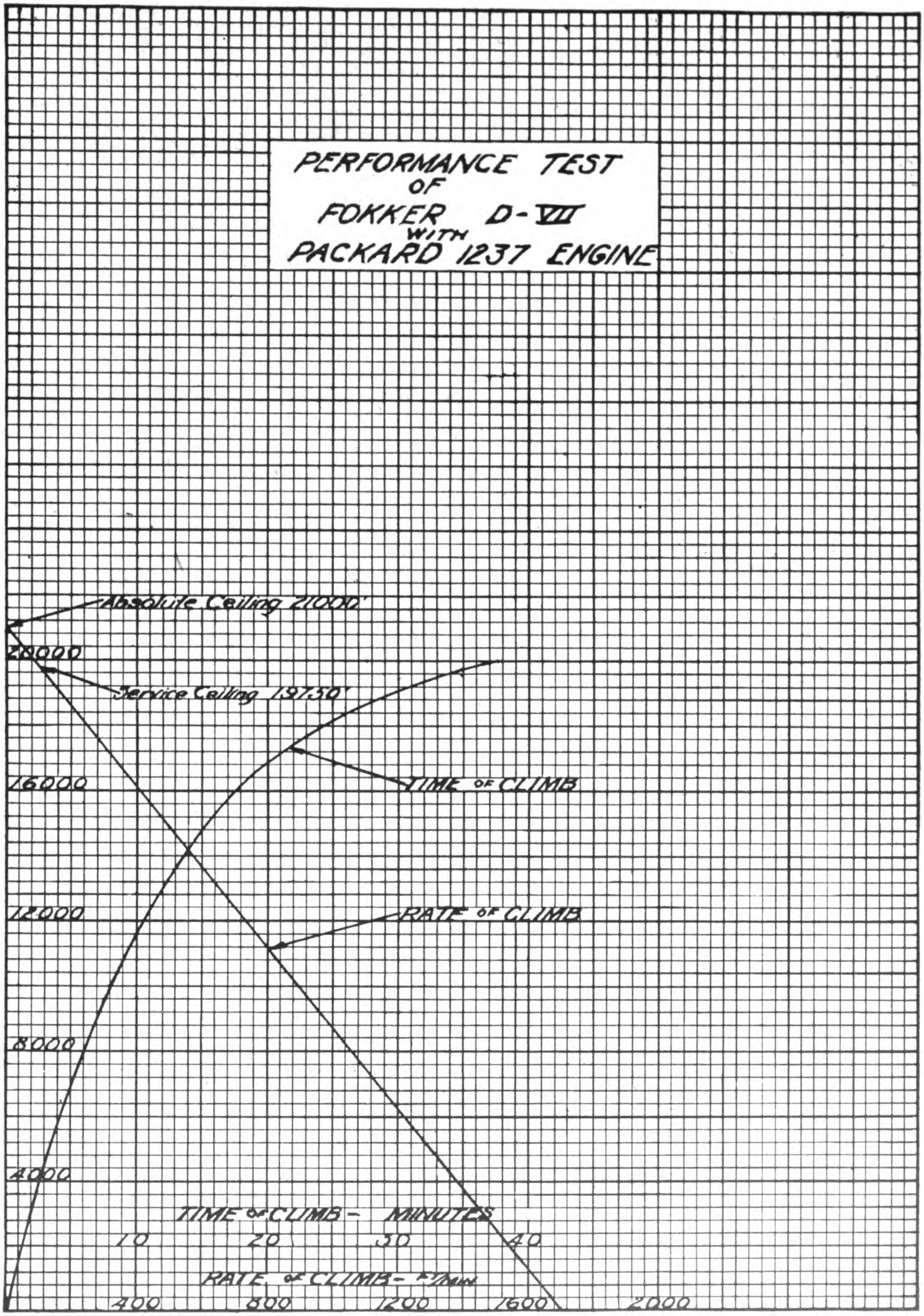

PERFORMANCE TEST
OF
FOKKER D-VII
WITH
PACKARD 1237 ENGINE
Absolute Ceiling 21000'
20000
Service Ceiling 19750'
16000
TIME OF CLIMB
12000
RATE OF CLIMB
8000
4000
TIME OF CLIMB - MINUTES
10
20
30
40
RATE OF CLIMB - FT/MIN
400
800
1200
1600
2000

FIG. 1.

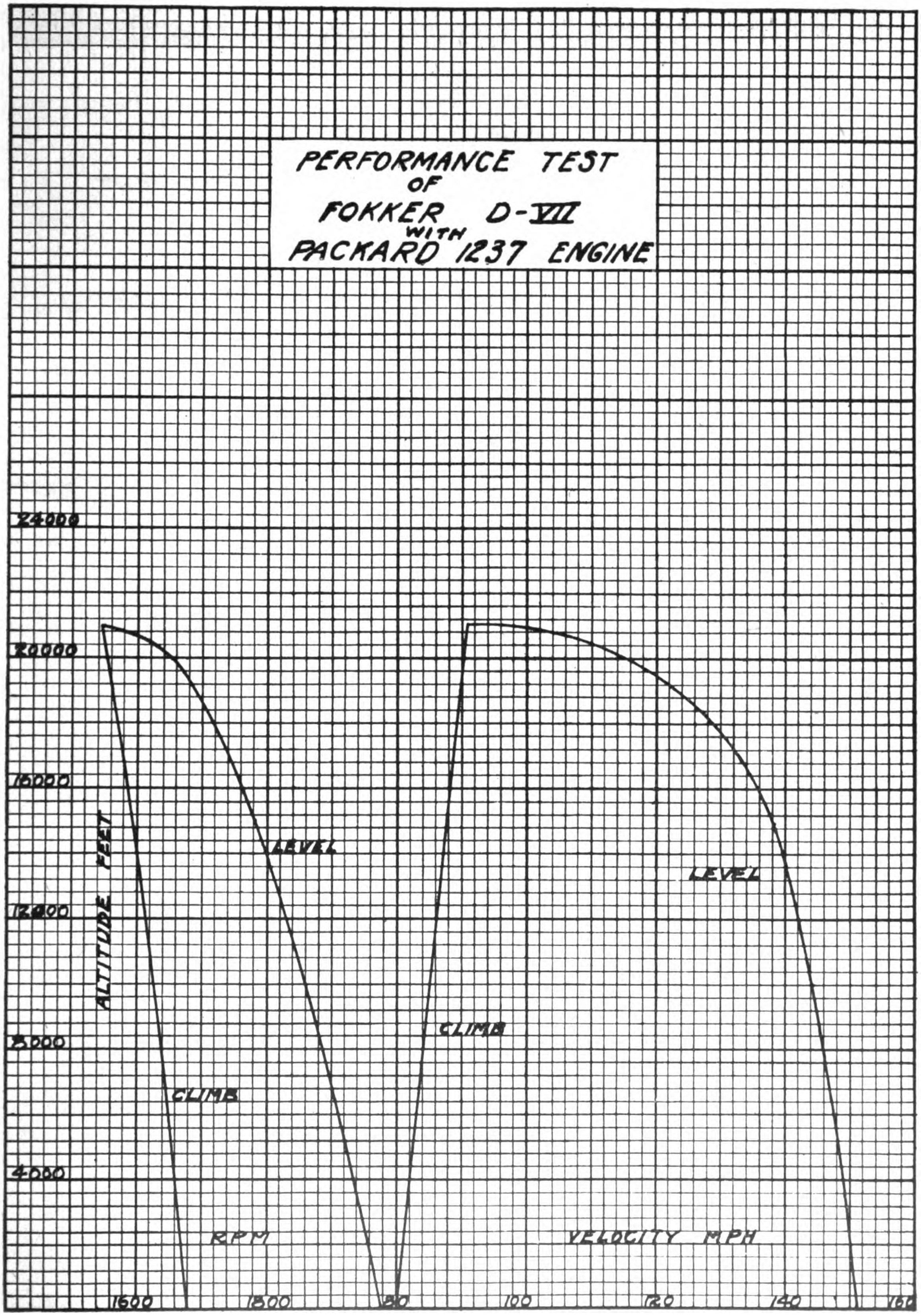

PERFORMANCE TEST
OF
FOKKER D-VII
WITH
PACKARD 1237 ENGINE
24000
20000
16000
12000
8000
4000
ALTITUDE FEET
LEVEL
CLIMB
LEVEL
CLIMB
RPM
VELOCITY MPH
1600
1800
80
100
120
140
160

FIG. 2.

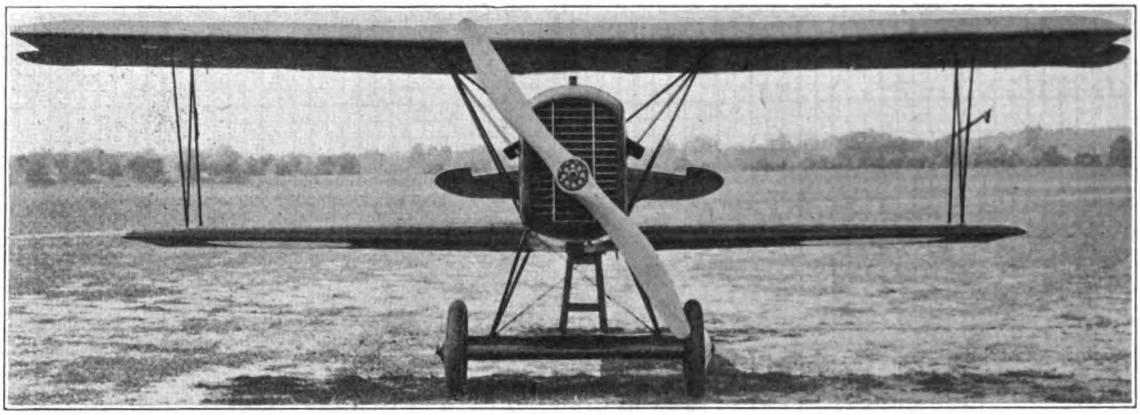


FIG. 3.

FIG. 4.

FIG. 5.

File D 52.41 / Liberty / 222

McCOOK FIELD REPORT, SERIAL No. 1732

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 311

THE DETERMINATION OF A CARBURETOR SETTING FOR THE LIBERTY ENGINE FOR DIRIGIBLE USE

(POWER PLANT SECTION REPORT)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
July 29, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

THE DETERMINATION OF A CARBURETOR SETTING FOR THE LIBERTY ENGINE FOR DIRIGIBLE USE.

OBJECT OF TEST.

The purpose of this test was to develop a carburetor setting for the Liberty 12-cylinder engine adapting it for dirigible service.

SUMMARY AND CONCLUSIONS.

The recommended carburetor setting to be used in conjunction with the Zenith U. S. 52 carburetors is 24-millimeter chokes, 1.15-millimeter main jets, and 1.20-millimeter compensator jets. This setting is to be used to obtain approximately 280 horsepower at 1,400 revolutions per minute. At this output the Liberty engine will weigh 3 pounds per horsepower.

INTRODUCTION.

The main performance characteristics required of a dirigible engine are durability (even if obtained at the sacrifice of low weight per horsepower), low-fuel comsumption over a wide range of speed, ability to run smoothly throughout the speed range, and a low-idling speed. By choking down the output to about 280 horsepower and reducing the normal full throttle speed from 1,700 revolutions per minute to 1,400 revolutions per minute (at this output the Liberty engine will weigh 3 pounds per horsepower), it is believed that the standard Liberty "12" engine will fulfill these requirements in a satisfactory manner.

A further reason for reducing the output to 280 horsepower is that this is the power output of the Renault engines, which are now in use on several Army dirigibles and which will be replaced by Liberty engines.

METHOD OF TEST AND DISCUSSION OF RESULTS.

A Liberty "12" cylinder engine, with 6½:1 compression ratio, was mounted on the dynamometer. The engine was equipped with standard Liberty Zenith Model U. S. 52 carburetors with standard Liberty settings of 36-millimeter chokes, 1.65-millimeter main jets, and 1.70-millimeter compensator jets. Domestic aviation gasoline (War Department Specification No. 2-40) was used, unblended with any antidetonating compound. It was proposed to eliminate detonation by throttling and in that manner take advantage of the higher compression to obtain low fuel consumption. With the output throttled, as proposed, to 280 horsepower at 1,400 revolutions per minute, detonation was encountered, and since it was not desired to use antidetonating compounds further trials with the high compression were abandoned.

A standard Liberty 12-cylinder engine, with standard compression ratio and standard Liberty carburetor setting, was next mounted on the dynamometer. A plate, with a hole 1.250 inches in diameter, was placed above the carburetor in each intake manifold, which on several check runs, it was determined, limited the power output to 280 horsepower at 1,400 revolutions per minute. With this arrangement a corrected output of 291 horsepower and a fuel consumption of 0.470 pound per horsepower per hour were obtained at 1,400 revolutions per minute. Data for these runs are not included in this report, as this method of throttling, it was believed, would probably cause loading up of fuel at the plate, with consequent irregular operation of the engine.

A series of check runs was then made on the same engine to obtain the carburetor setting with a reduced carburetor choke which would give approximately 280 brake horsepower at 1,400 revolutions per minute. Two full-power runs, a friction horsepower run, and two propeller load runs were made with 24-millimeter chokes, 1.10-millimeter main jets, and 1.30-millimeter compensator jets, which was determined to be the proper setting. Data for these runs, a power curve and a drawing of the Venturi choke, are given on pages 4 to 8. The full-power curve shows an output of 294 brake horsepower and a fuel consumption of 0.460 pound per horsepower per hour at 1,400 revolutions per minute. It will be noted that the fuel economy on propeller load operation is good, even at the lower speeds.

On completion of the above runs it was decided to make additional runs with a larger main jet, as it was feared that in flight service the 1.10-millimeter jet might give a mixture so lean as to interfere with acceleration and cold-weather operation. The main jet was therefore increased to 1.15 millimeters. To give a more balanced setting, the compensator was reduced to 1.20 millimeters. The choke size was not changed.

It was found expedient further to conduct these tests on a 6-cylinder Liberty engine instead of a 12-cylinder. By using an adapter it was possible to feed all six cylinders from one Zenith U. S. 52 carburetor, each barrel of which fed a bank of three cylinders. In this manner all the conditions obtained on a 12-cylinder engine were exactly reproduced, except that the power output was one-half of that of a 12-cylinder engine. Full-power runs at normal speed were made on the dynamometer both with the original setting and with the enriched setting. As shown on page 6, the power output with the two settings is approximately the same at 1,400 revolutions per minute with a specific fuel consumption for the richer

setting of 0.520 pound per brake horsepower per hour at full rich operation. Tests for the performance of this setting as regards acceleration, idling, etc., were made on the torque stand. The acceleration and operation at all speeds on the torque stand was entirely satisfactory. The lowest idling speed obtained was 210 revolutions per minute.

It will be noted that the power output obtained with this revised setting (allowing for the difference in the number of cylinders) is practically the same as was first obtained on the dynamometer runs on the 12-cylinder engine with the "24-110-130" setting though the fuel consumption in the full rich position is slightly higher. A leaner mixture can, of course, be obtained by use of the mixture control. For these reasons the power curves attached herewith for the "24-110-130" setting also fairly represent the performance that can be obtained with the "24 115 120" setting, provided the altitude control is properly used.

RECOMMENDATIONS.

It is recommended that for dirigible service the standard Liberty 12-cylinder engine be equipped with the following carburetor setting: 24-millimeter chokes, 1.15-millimeter main jets, and 1.20-millimeter compensator jets. This setting gives slightly over 280 brake horsepower at 1,400 revolutions per minute with good fuel economy and smooth operation at all speeds. To obtain maximum fuel economy, the carburetor mixture control must be properly used.

STANDARD LIBERTY "12" WITH FIRST (LEAN) SETTING.

Full-power runs.

FIRST RUN.

R. p. m.	Actual—		Corrected—		Water.		Oil.			Carb. air temp. °F.	Man vac., in. hg.	Fuel cons.	
	Brake load, lbs.	B. hp.	Hp.	B. m. e. p., lbs. per sq. in.	Temp. °F.		Temp. °F.		Pressure, lbs. per sq. in.			Sec. for 3 lbs.	Lb. per hp.-hr.
					In.	Out.	In.	Out.					
1,000	704.0	234.6	240.4	115.4	137	173	91	104	43	85	1.9	103.0	0.447
1,100	692.0	253.7	260.0	113.4	145	174	92	104	44	85	2.2	93.8	.454
1,190	672.0	266.5	273.0	110.1	140	170	93	106	45	85	2.6	86.8	.467
1,290	643.5	276.8	283.7	105.5	141	169	94	109	45	85	3.1	84.8	.460
1,390	617.5	286.2	293.2	101.2	141	170	94	115	46	85	3.5	81.6	.463
1,490	590.0	293.0	300.3	96.8	142	168	95	119	47	85	3.8	80.8	.456
1,600	567.0	302.5	310.0	93.0	144	170	96	124	47	85	4.2	78.4	.456

SECOND RUN.

1,000	700.0	233.2	239.0	114.7	142	175	96	107	44	86	1.9	100.0	0.463
1,090	691.0	251.1	257.4	113.3	138	171	96	107	44	86	2.2	93.2	.462
1,190	671.5	266.4	273.0	110.1	137	169	97	108	45	86	2.6	88.2	.460
1,290	643.0	276.5	283.4	105.4	143	170	97	109	45	86	3.1	83.8	.466
1,400	617.5	288.2	295.3	101.2	145	175	97	113	46	86	3.5	82.6	.454
1,490	588.0	292.0	299.3	96.4	141	168	97	118	46	86	3.8	79.6	.465
1,590	568.5	301.3	308.8	93.3	141	167	98	122	47	86	4.1	78.6	.456

Data for both runs:
- Length of brake arm, 21 inches.
- Kind of oil used, Spec. No. 2-23.
- Kind of fuel used, domestic aviation gasoline.
- Specification, No. 2-40.
- Specific gravity of gasoline, 0.697 at 63.4° F.
- Spark plugs used, a. c.
- Barometer, 29.19 in. hg.
- Position of altitude control, 6.0 (6.75 = full rich position).
- Zenith U. S. 52 carburetor setting:
  - Choke, 24 mm.
  - Main jet, 1.10 mm.
  - Compensator jet, 1.30 mm.
  - Jet flow under head of 50 centimeters—
    - Main jet, 15.98 imperial pints per hour.
    - Compensator jet, 23.46 imperial pints per hour.

Propeller load runs.

FIRST RUN.

R. p. m.	Actual— Brake load, lbs.	Actual— B. hp.	Corrected hp.	Water. Temp. °F. In.	Water. Temp. °F. Out.	Oil. Temp. °F. In.	Oil. Temp. °F. Out.	Oil. Pressure, lbs. per sq. in.	Carb. vac., in. hg.	Man. vac., in. hg.	Fuel cons. Sec. for 3 lbs.	Fuel cons. Lb. per hp.-hr.
1,410	613.0	288.0	295.2	141	168	97	110	45	86	3.5	81.2	0.462
1,280	534.0	227.8	233.5	143	167	98	112	45	86	3.8	107.8	.440
1,190	456.0	180.8	185.3	145	168	98	111	44	87	4.5	133.6	.447
1,090	380.0	138.1	141.5	148	171	99	109	44	87	6.4	162.0	.483
1,010	314.0	105.7	108.3	148	168	99	107	44	87	8.4	199.0	.514
900	254.0	76.2	78.1	147	169	99	105	43	87	11.1	258.3	.549
810	202.0	54.5	55.9	150	169	99	102	40	88	13.2	325.2	.610

SECOND RUN.

1,390	609.5	282.5	289.5	143	168	97	115	44	87	3.5	80.0	0.478
1,290	536.0	230.5	236.3	145	168	99	115	44	87	3.7	104.8	.447
1,180	454.0	178.6	183.0	145	167	99	114	43	87	4.3	129.6	.467
1,100	381.0	139.7	143.2	148	168	99	111	43	87	5.8	156.6	.494
1,010	315.0	106.1	108.7	148	170	100	108	43	87	8.0	194.4	.522
890	254.0	75.3	77.2	149	172	100	107	42	87	10.7	256.0	.561
790	200.0	52.7	54.0	148	169	100	110	34	87	13.1	323.4	.634

Data for both runs:
- Length of brake arm, 21 inches.
- Kind of oil used, Spec. No. 2-23.
- Kind of fuel used, domestic aviation gasoline.
- Specification, No. 2-40.
- Specific gravity of gasoline, 0.697 at 63.4° F.
- Spark plugs used, a. c.
- Barometer, 29.19 in. hg.
- Position of altitude control, 6.0 (6.75 = full rich position).
- Zenith U. S. 52 carburetor setting:
  - Choke, 24 mm.
  - Main jet, 1.10 mm.
  - Compensator jet, 1.30 mm.
  - Jet flow under head of 50 centimeters—
    - Main jet, 15.98 imperial pints per hour.
    - Compensator jet, 23.46 imperial pints per hour.

LIBERTY "12" ENGINE.

FRICTION HORSEPOWER RUN.

R. p. m.	Friction load, lbs.	Friction horsepower.	B. hp. (from curve).	Mech. eff. per cent.	Water. Temp. °F. In.	Water. Temp. °F. Out.	Oil. Temp. °F. In.	Oil. Temp. °F. Out.	Oil. Pressure, lbs. per sq. in.
800	67	17.9	....	....	165	167	100	118	36
900	71	21.3	....	....	168	170	100	118	40
1,000	74	24.7	239	90.6	167	170	100	120	42
1,100	79	29.0	259	90.0	167	170	100	124	43
1,200	84	33.6	274	89.0	167	170	100	128	43
1,300	90	39.0	285	88.0	167	170	100	131	44
1,400	95	44.4	294	87.0	167	170	100	133	45
1,500	101	50.5	302	85.6	167	170	101	137	46
1,600	109	58.2	308	84.2	167	170	101	138	46

Room temperature, 85° F.
Zenith U. S. 52 carburetor setting.—Choke, 24 mm.; main jet, 1.1 mm.; comp. jet, 1.3 mm.

LIBERTY "6" ENGINE.

Check full-power runs at 1,400 R. p. m.

FIRST RUN (first setting determined).

R. p. m.	Actual— Brake load, lbs.	Actual— B. hp.	Corrected— Hp.	Corrected— B.m.e.p., lbs. per sq. in.	Water. Temp. °F. In.	Water. Temp. °F. Out.	Oil. Temp. °F. In.	Oil. Temp. °F. Out.	Oil. Pressure, lbs. per sq. in.	Carb. air temp. °F.	Rear man. vac., in. hg.	Front man. vac., in. hg.	Fuel cons., lb. per hp.-hr.
1,420	295.0	139.6	143.2	96.9	150	166	99	104	26	86	3.5	3.9	0.499
1,420	295.5	139.8	143.4	97.1	155	171	101	107	26	86	3.5	3.9	0.492

Zenith U. S. 52 carburetor setting.
- Choke, 24 mm.
- Main jet, 1.10 mm.
- Compensator jet, 1.30 mm.

Jet flow under head of 50 centimeters:
- Main jet, 15.98 imperial pints per hour.
- Compensator jet, 23.46 imperial pints per hour.

SECOND RUN (enriched setting).

1,420	299.0	141.5	145.2	98.2	154	167	104	105	26	86	3.5	4.0	0.511
1,410	300.0	141.0	144.6	98.5	155	170	106	108	26	86	3.5	4.0	0.523
1,400	300.5	140.2	143.8	98.8	152	.168	106	110	26	86	3.5	4.0	0.526

Zenith U. S. 52 carburetor setting:
- Choke, 24 mm.
- Main jet, 1.15 mm.
- Compensator jet, 1.20 mm.

Jet flow under head of 50 centimeters:
- Main jet, 17.34 imperial pints per hour.
- Compensator jet, 20.16 imperial pints per hour.

Data for both runs:
- Length of brake arm, 21 inches.
- Kind of oil used, Spec. No. 2-23.
- Specific gravity of gasoline, 0.697 at 63.4°F.
  - Spark plugs used, a. c.
  - Barometer, 29.17 in. hg.
  - Altitude control, full rich.

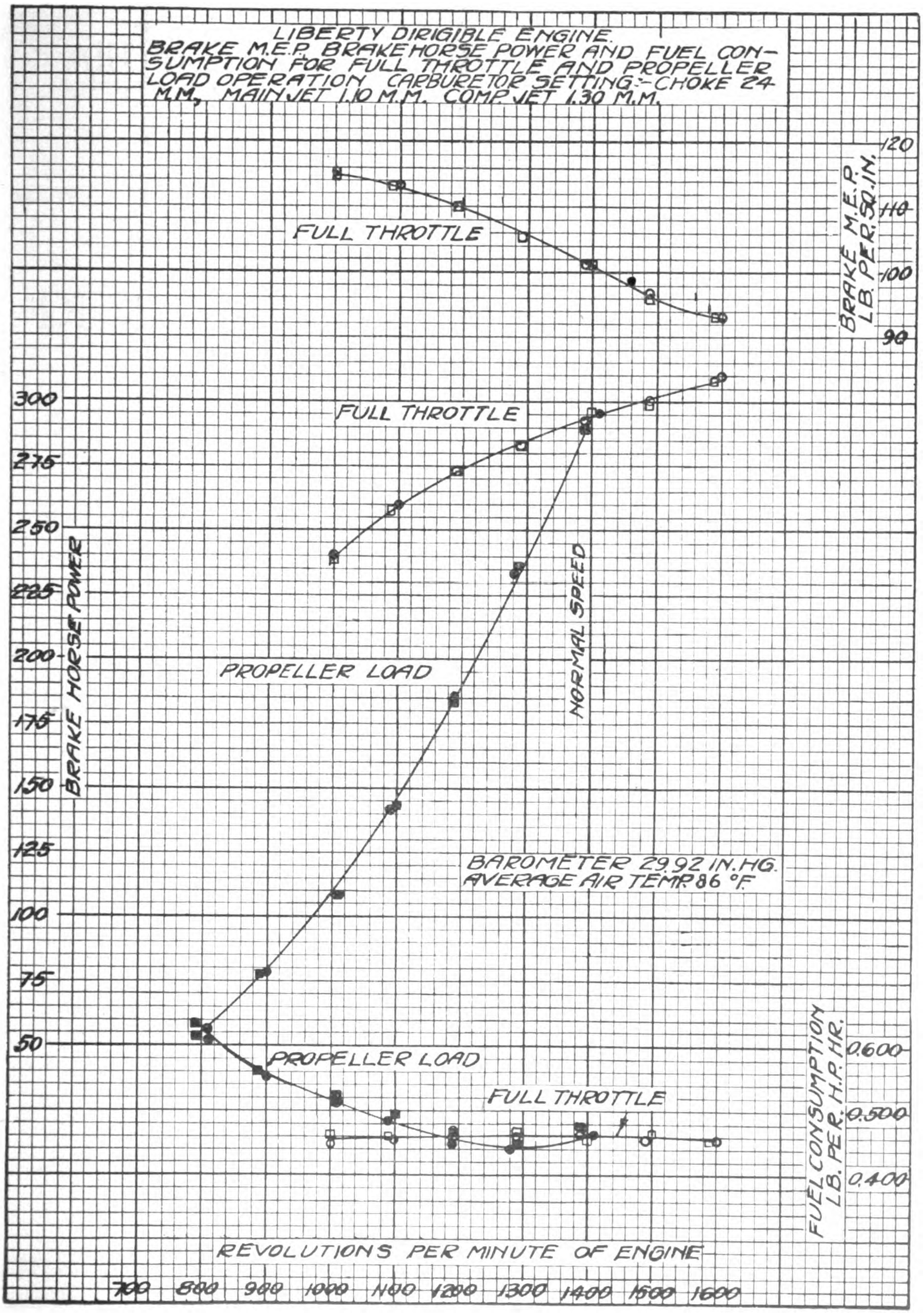
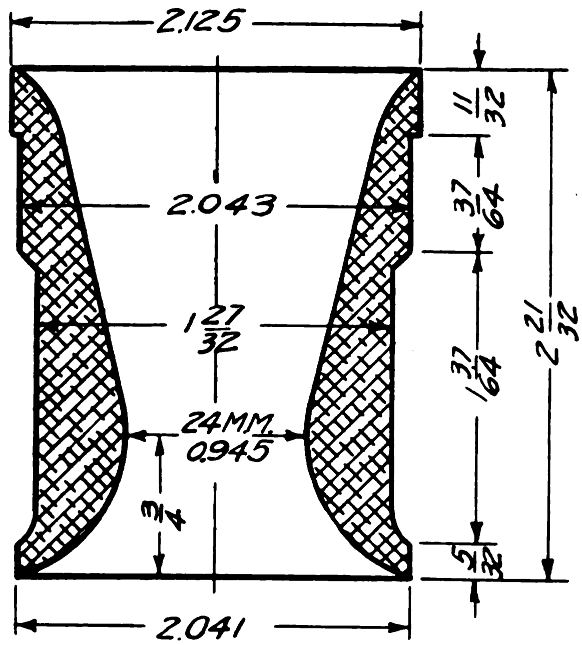

LIBERTY DIRIGIBLE ENGINE.
BRAKE M.E.P. BRAKE HORSE POWER AND FUEL CONSUMPTION FOR FULL THROTTLE AND PROPELLER LOAD OPERATION CARBURETOR SETTING:- CHOKE 24 M.M., MAIN JET 1.10 M.M. COMP. JET 1.30 M.M.
FULL THROTTLE
BRAKE M.E.P. LB. PER SQ. IN.
120
110
100
90
FULL THROTTLE
300
275
250
225
200
175
150
125
100
75
50
BRAKE HORSE POWER
NORMAL SPEED
PROPELLER LOAD
BAROMETER 29.92 IN. HG.
AVERAGE AIR TEMP. 86 °F.
PROPELLER LOAD
FULL THROTTLE
FUEL CONSUMPTION LB. PER H.P. HR.
0.600
0.500
0.400
REVOLUTIONS PER MINUTE OF ENGINE
700
800
900
1000
1100
1200
1300
1400
1500
1600

Fig. 1.



NOTE.—All dimensions except as noted are in inches.
FIG. 2.—Liberty dirigible engine. 24 mm. choke for Zenith U. S. 52 carburetor.

File D 52.332/21

McCOOK FIELD REPORT SERIAL No. 1734

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 312

DESIGN OF LARGE TRUSSED RIBS

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
June 2, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INDEX.

DESIGN OF LARGE TRUSSED RIBS.

The development of large bombers and passenger airplanes brings up the problem of the design of large ribs of adequate strength and minimum weight. Experience has proven that the ply-wood type of construction with web cut-outs is uneconomical for large ribs. The use of a trussed-web construction may be made economical and it is the purpose of this report to describe satisfactory methods of design. To illustrate the application of the principles of design, an example is worked out in detail in the Appendix. The example chosen is the design of a duralumin trussed rib for a 4,760-pound corps observation airplane.

LOAD DISTRIBUTION ALONG THE CHORD.

Ribs should be designed for two conditions of loading corresponding to different angles of attack of the wings.

The first condition of loading considered is a triangular distribution with the apex 25 to 33 per cent of the chord to the rear of the leading edge of the wing. The positions of the centers of pressure for these distributions are 41.6 and 44.5 per cent, respectively, from the leading edge. The location of the apex of the triangular loading diagram within the limits designated is chiefly a matter of judgment. Experience has shown that the lower chord member in the second panel to the rear of the front spar is the limiting chord member, and that the section is determined by the direct stress and bending moment just to the left of the second panel point from the front spar. The apex of the triangular loading diagram should be located close to this panel point in order to secure a maximum value of the combined stresses. The center of pressure for high speed is farther back than this, but the loading stated gives the most severe stresses in the limiting compression chord member, and when combined with a load factor slightly in excess of that for low incidence will prove the limiting case for the web members. This condition of loading will be referred to as Case A.

The second condition of loading to be investigated is for high incidence, and will be referred to as Case B. From a study of the load distribution along the chord for various airfoils it was found that the curve representing the variation in this loading could be closely approximated by a parabola. Figure 1 shows a typical pressure distribution curve for high incidence, and the parabolic curve assumed to represent it. Figure 2 gives the location of the vertex of the parabola in terms of the wing chord for various positions of the center of pressure. The position of the center of pressure for high incidence for a given wing is that at which the center of pressure reaches its most forward position except for wings in which Ky becomes a maximum before the center of pressure reaches that position. In the latter case the position of the center of pressure corresponding to maximum Ky is used. The construction of the curve shown in Figure 2 is taken up in detail in the Appendix.

The third condition of loading is that due to the initial tension in the fabric due to the action of the dope. The stresses in the members of the rib due to high incidence and low incidence loadings are superimposed upon the stresses due to fabric tension. The stresses due to fabric tension are considered by applying two equal and opposite thrusts with the same line of action, the point of application of one being at the leading edge and of the other at the trailing edge of the wing. The magnitude of each thrust is equal to the rib spacing in inches multiplied by twice the fabric tension per linear inch measured parallel to the direction of the spars. A value of 3 to 4 pounds per linear inch for fabric is recommended in Pippard and Pritchard's "Aeroplane Structures." The Materials Section at McCook Field have conducted experiments which indicate that the average value of this stress is 2 to 2½ pounds per linear inch with a maximum of 5 pounds per linear inch. Four pounds per linear inch represents a conservative design value for the fabric tension.

DISTRIBUTION OF LOAD BETWEEN FLANGES OF RIB.

The distribution of the load between the flanges of the rib is dependent upon the manner in which the fabric is attached to the ribs. Two cases should be considered: (1) In which the upper surface of the fabric is attached directly to the upper flange and in which the lower surface of the fabric is attached to the lower flange, and (2) in which the lacing cords pass around both flanges of the rib. In the first case the upper flange of the rib will receive about 70 per cent of the total load, and the lower flange will receive the remainder. In the second case the entire load will be transmitted to the lower flange. The distribution of the load between the flanges has an important influence on the design of the flange members, but a negligible effect on the design of the web members.

LOAD FACTORS.

The load factor for the ribs should be slightly in excess of the load factor for the rest of the wing structure in accordance with the well-established principle of structures that the subordinate parts of a structure should be stronger than the main parts. For high incidence and low incidence loading the load factors should be about one-half a factor greater than the corresponding load factors for the wing structure. Case A loading is intermediate between the low and high incidence condition and a reasonable load factor for the wing structure would be a mean between the load factors for the two types of loading.

No load factor should be applied to the stresses produced by fabric tension, due to the fact that the strains in the

fabric in the longitudinal direction of an airplane's axis does not increase materially in flight since the fabric is attached all along the ribs.

RIB SPACING.

The spacing of ribs is taken up fully in the "Structural Analysis and Design of Airplanes," page 118, and in Pippard and Pritchard's "Aeroplane Structures," pages 189 and 190. The article referred to states that rib spacing is a function of wing loading and maximum speed, and that rib spacing for large airplanes is limited by fabric strength rather than rib design. For large bombers, corps observation airplanes, and large passenger airplanes the minimum rib spacing outside of the slip stream should be about 15 inches. Within the slip stream of the propeller the spacing should be reduced to approximately 70 per cent of the normal spacing to take into consideration the increased lift due to the slip stream effect.

The application of a method to serve as a guide in the determination of the maximum rib spacing is taken up in detail in the Appendix.

TYPES OF RIB TRUSS.

Howe: Diagonal web members in compression. Vertical web members in tension.

Pratt: Diagonal web members in tension. Vertical web members in compression.

Warren: Web members alternately tension and compression.

Subdivided Warren: Diagonal and vertical web members alternately tension and compression.

For thin wing sections like the USA-5 and RAF-15 it is advisable to use the Warren truss for economy of material.

For thick wing sections like the USA-27 there is no appreciable advantage in strength between the Howe, Pratt, and subdivided Warren types of truss. The subdivided Warren or Howe truss in which the diagonal web members adjacent to the spars are in compression is recommended in general, however, because of the increased rigidity of the connection between the rib and spar made possible. In general it is much better to have a thrust exerted by the rib against the spar than a pull, and this is effected by the use of a Howe or subdivided Warren truss.

The Pratt type of truss has an application in metal construction in which the two diagonal members adjacent to each spar are continuous. The diagonals may be flattened out under the spars and riveted to the bottom flanges of the spar, thus securing a rigid connection.

DETERMINATION OF STRESSES IN MEMBERS.

The first step in determining the direct stresses in the members of the rib truss is to obtain the panel concentrations for the high and low incidence loadings. These are obtained from the curves of loading by assuming that the sections of the chord between panel points are simple beams. The load at each panel point would then be approximately equal to the area under the loading curve bounded by ordinates half way to the adjacent panel points. Seventy per cent of the load should be considered acting at the upper panel point and 30 per cent at the lower panel point, and this distribution of the load would apply to the reactions as well. The direct stresses will not be effected seriously if the entire load is assumed to act at the upper surface. A diagonal should be assumed in place of each spar to secure continuity of truss action, and one-half of the load should be applied at the panel points adjacent to the imaginary diagonal member. Once the panel concentrations have been determined and the thrust due to fabric tension ascertained, it is simply a question of making a graphical determination of the direct stresses considering the rib a pin-jointed structure.

The bending moments in the chord members due to the distributed load are calculated by considering the chord a straight beam continuous over panel points between spars. The distribution of the load between the chords for different methods of attaching the fabric to the ribs has been taken up on page 1.

The bending moments in the chord members due to initial eccentricities caused by the curved outline of the rib may be safely ignored.

DESIGN OF WEB MEMBERS.

The design of web members may be classified under two heads, (1) those which are symmetrical about an axis in the plane of the truss, and (2) those which are unsymmetrical about that axis.

(1) The web members should be designed for the limiting stress in high incidence, low incidence, or reversed flight. The stresses are reversed in reversed flight, and their magnitude may be taken as 50 per cent of the stresses in high incidence. This assumption is based on the fact that the center of pressure is well forward in reversed flight, and that the relation between the load factors for reversed flight and high incidence is somewhat less than 50 per cent.

The column formulæ recommended for the design of the compression web members are the Johnson parabolic column formula and the Euler column formula within their ranges. The Johnson formula ceases to be effective when the allowable unit stress falls below 50 per cent of the yield point of the material in compression. Below that value the Euler column formula should be used.

The Johnson formula is as follows:

$$\frac{P}{A}=f-\frac{f^2}{4c\pi^2E}\left(\frac{L}{\rho}\right)^2$$

f=yield point of material.

c=a constant depending on the fixity of the ends of the column.

The remainder of the terms have their ordinary significance.

The Euler column formula is as follows:

$$\frac{P}{A}=\frac{c\pi^2E}{(L/\rho)^2}$$

c=a constant with same values as in the parabolic formula.

The fixity coefficients for the compression web members of reinforced ply-wood truss ribs have been found in test to be conservatively represented by the following values: 1.25 in a plane normal to the rib, and 2 in the plane of the rib. For steel web members riveted to the flanges of the rib, it is recommended that a fixity coefficient of one

should be used in both planes. In the Appendix there are several combined parabolic and Euler column curves for spruce, duralumin, and mild steel. Figures 3 and 4.

When reinforced ply-wood truss ribs are used, the design of the web members is based on the following considerations:

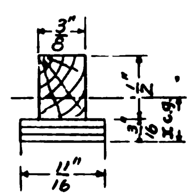
(*a*) Sufficient gluing surface at the extremities of each web member between the ply wood and the reinforcing strip to develop the reinforcing strip before the ply-wood gusset narrows down to the width calculated for column strength.

(*b*) Sufficient sectional area to develop the tensile or compressive stress. Figure 5 has been reproduced from a report of the Haskelite Research Laboratory, and gives the allowable tensile and compressive resistance of various ply woods when the applied load makes different angles with the direction of the face grains.

In riveted metal construction there must be sufficient net sectional area at the extremities of compression members so that the yield point of the material for compression members or the tensile strength of the material for tension members will not be exceeded. The allowable bearing values of rivets of various diameters on duralumin and steel plate and the shearing values of one-eighth-inch rivets of steel and duralumin are tabulated in Tables IV and V of the Appendix.

(2) When the web members are unsymmetrical about an axis in the plane of the truss, the design of the web members is somewhat different. An example is found in reinforced ply-wood truss rib construction in which reinforcing is used on only one side of the web. The stress is applied to the web members through strips through the glued surfaces. Due to the lack of symmetry of the web members about an axis in the plane of the rib, the stress is applied eccentrically, causing bending stresses in the compression members. A method of analysis of columns subjected to combined bending and direct stresses, known as the method of secondary deflections, has given excellent results and is strongly recommended for the design of compression web members of an unsymmetrical section as stated. To illustrate its use an example will be worked out in detail. The example chosen is the design of a vertical web member for a 15-foot 0-inch reinforced ply-wood truss rib.

Stress $= -223$ pounds.
Length $= 18.85$ inches.
Effectiveness of ply wood referred to spruce $= 0.435$.
Effective area $= 0.2436$ square inch.
$X_c.g. = 0.358$ inch.
$I_c.g. = 0.00926$ inch.^{4}
$r = 0.195$.



The primary eccentricity is equal to the sum of the initial eccentricity in the member and the deflection due to the load. The former term is equal to the distance from the center line of the ply wood to the center of gravity of the section, while the latter term is equal to the deflection at the center of a beam subjected to terminal couples.

$$\text{Primary deflection} = \left(X_{c.g.} - \frac{3}{32}\right) + \frac{ML^2}{8EI} = (0.358 - 0.094) + \frac{223 \times 0.264 \times \overline{18.85}^2}{8 \times 1,600,000 \times 0.00926} = 0.440 \text{ inch.}$$

Primary bending moment $= 223 \times 0.440 = 98.2$ inch-pounds.

The next step is to determine the uniform load which will produce the same bending moment at the center of a beam freely supported at the ends.

$$98.2 = \frac{wL^2}{8};\quad w = 2.21 \text{ pounds per linear inch.}$$

Deflection due to uniform load

$$= \frac{5}{384}\frac{wL^4}{EI} = \frac{5}{384} \times \frac{2.21 \times \overline{18.85}^4}{1,600,000 \times 0.00926} = 0.246 \text{ inch.}$$

Ratio between secondary and primary eccentricities

$$= \frac{0.246}{0.440} = 0.558$$

The total bending moment is the sum of a series which may be determined as follows:

$$M = \frac{M\text{ primary}}{1 - 0558} = \frac{98.2}{0.442} = 223 \text{ inch-pound.}$$

f_c = fiber stress in direct compression $= \frac{223}{0.2436}$ = 920 pounds/square inch.

f_b = fiber stress in bending (compression fibers)

$$= \frac{223 \times 0.358}{0.00926} = \frac{8,625 \text{ pounds/square inch.}}{9,545 \text{ pounds/square inch.}}$$

f allowable

$$= \frac{f_b}{f_b + f_c}(F - C) + C = \frac{8,625}{9,545}(10,300 - 2200) + 2,200 = 9,525 \text{ pounds per square inch.}$$

The web members of the rib cited were designed throughout in accordance with this principle, and failure occurred in one of the web members when the applied test load was 4 per cent in excess of the designed load.

DESIGN OF CHORD MEMBERS.

The chord members are subjected to direct stresses due to truss action, and bending stresses due to beam action. The deflections between panel points due to the distributed load, and the initial eccentricities in the chords between panel points due to the wing section may be ignored. The fixity coefficient of the chord members in the plane of the rib may be taken as 2. In considering the strength of the chord at a panel point, column action should be allowed for by assuming that the chord is a column with a length equal to 25 per cent of the sum of the lengths of the adjacent panels. When reinforced ply-wood truss ribs are designed the actual section at a panel point including the gusset should be used in connection with the peak bending moment due to the distributed load. In such designs it is also advisable to investigate the stresses at a point on either side of the panel point where the normal section begins.

The allowable stresses due to combined bending and direct stresses are found by the following formula:

$$f_a = \frac{f_b}{f_b + f_c}(F - C) + C$$

f_a = maximum allowable combined fiber stress.
f_b = fiber stress in bending.
f_c = fiber stress in direct compression.
F = modulus of rupture material.
C = allowable fiber stress for column action alone.

In riveted metal construction the question arises as to the relative advantages of using (1) the same rivet for attaching two adjacent web members to the flanges or (2) of using a separate rivet for the attachment of each member.

The former method is especially adapted to tubular web member construction in which the web members may be slit back at each end along two diametrically opposite elements parallel to the axis of the tube. The flattened portions at the ends of each tube should grip the vertical webs of the flanges on each side and should be caught by the same rivet. To avoid eccentricities, the rivet hole should be located as near the center of gravity of the flange as possible.

For economy of production and structural reasons it is recommended that a separate attachment to the flanges should be used for the web members in construction in which these members are of a channel section. The intersection of the lines of action of the stresses in the web members at each panel point should be close to the center of gravity of the flanges in order to avoid serious eccentricities.

The relative advantages of the split versus the routed cap strip and the approved methods of connecting the ribs to the spars in wooden construction are considered fully in the "Structural Analysis and Design of Airplanes." The trend of present rib design is to use the routed cap strip and a tenoned web for the transfer of the shear to the spar. The split cap strip is preferable to the routed cap strip when the web of the rib is very thin because of the danger in the latter case of splitting the web by nailing. The use of steel clips to attach the cap strip to the spar has been discontinued.

In metal construction U-shaped and channel-shaped flanges have been found to be satisfactory. In duralumin the radius of curvature should not be less than four times the thickness of the metal.

The connection between the rib and spar may be constructed very rigidly in metal. In the Appendix, figures 6 and 7, are given details of the connection of a duralumin rib to a wooden spar, and the connection of a duralumin rib of a different construction to a metal spar. The use of metal ribs and wooden spars is not desirable in general, but in this particular case it was necessary to develop sufficient strength in the rib of the lower wing adjacent to the fuselage of the Martin bomber when subjected to stresses caused by the discharge of the 75 mm. cannon.

The complete design of a trussed metal rib is carried through in the Appendix.

COMPRESSION RIBS.

Compression ribs are subjected to vertical lift loads, and also to thrusts due to their action as struts in the drag truss. The portion of the compression ribs beyond the spars should be designed for the same stresses as occur in the other ribs. The portion between spars should be designed for combined vertical loads equal to those which the other ribs are subjected to, and also for the compression in the drag truss. The following procedure is recommended for the design of trussed compression ribs.

1. Apply two equal and opposite thrusts of unity in the plane of the drag truss to the ribs. The points of application of the forces are at the spars.
2. Distribute the loads of unity to the flanges in the inverse relation of their vertical distances from the flanges.
3. Solve the stresses in the portion of the rib between spars for the thrust.
4. Multiply the stress due to a unit thrust by the actual compression in the compression rib and combine these stresses with the stresses due to the vertical lift loads.
5. Design the compression rib for the combined stresses.

In addition the compression ribs stabilize the spars against twisting, but these stresses are indeterminate.

TYPES OF COMPRESSION RIBS.

In wood the double-web, cruciform, and box spar construction with the same profile as the other ribs have application. The double-web type may be designed as recommended above. The other two types should be designed as laterally loaded columns with an unsupported length equal to the distance between spars. The direct stress would be equal to the compression from the drag truss and the lateral load would be equal to the distributed load (Case A).

In metal construction it would in most cases be advisable to use the same form of construction as the spars.

FALSE (NOSE) RIBS.

False ribs should be used between main ribs from the leading edge to the front spar. The main function of these ribs is to maintain the correct airfoil section. The members of the false rib should be of the same size as the corresponding members of the main ribs, and should have a rigid connection to the spar. "The use of thin veneer or ply wood on the upper wing surface between the leading edge and the front spar, and preferably extending the entire length of the wing, is almost essential on airplanes of a speed greater than 120 miles per hour. For lower speed airplanes only the slip-stream length need be covered. Mahogany ply wood three sixty-fourths inch thick has proved very satisfactory for this purpose. When no such reinforcing is used the rib spacing should be somewhat closer than when the recommended reinforcing is present." [1]

Special reference should be made to Air Service Information Circular, Vol. 3, No. 212, entitled "Experimental Reinforced Plywood Truss Ribs." This report is a summary of the Forest Products Laboratory's work on the design of ribs with a 15-foot chord for the Navy Department, and includes the following types of construction:

1. Wrapped veneer strap.
2. Twisted veneer strap.
3. Navy design.
4. Pratt truss with individual web members.
5. Double Pratt truss with individual web members, and the Warren truss with individual web members.

This report also states what has been accomplished with the Barling, Handley-Page, and Glenn Martin ribs. The most important part of the report states the development which has been made in the design of reinforced ply-wood truss ribs, and the superiority of this construction over all other types of wood construction so far developed.

References.—Structural Analysis and Design of Airplanes, Engineering Division, Air Service. Aeroplane Structures, A. J. Pippard and J. L. Pritchard.

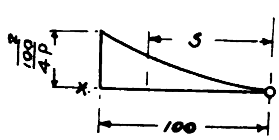
[1] From Structural Analysis and Design of Airplanes.

APPENDIX.

CONSTRUCTION OF FIGURE 2.

Figure 2 gives the location of the vertex of a parabola representing the variation in pressure along a wing chord in high incidence for various positions of the center of pressure ranging from 0.250 to 0.340 of the wing chord. The curve is determined as follows:

First consider the case in which the vertex of the parabola is at the trailing edge. See sketch (a).



Sketch (a).

Determine s=distance to center of gravity of the area under the parabola

$$s=\frac{\int x\,dm}{\int dm} \text{ where } dm=K\,dxdy \qquad K \text{ assumed}=1$$

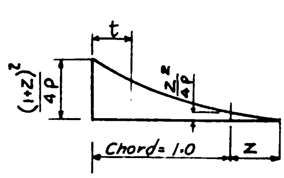
$$s=\frac{\int_0^{100}\int_0^{\frac{x^2}{4P}} x\,dxdy}{\int_0^{100}\int_0^{\frac{x^2}{4P}} dxdy} \quad \text{as the equation of the parabola is } x^2=4\,Py$$

s= 75

Determine A=area under the parabola.

$$A=\int dm=\int_0^{100}\int_0^{\frac{x^2}{4P}} dxdy=\frac{x^2}{4P}\times\frac{x}{3}$$

Next consider the case in which the vertex of the parabola is in the rear of the trailing edge.



Let t=distance to center of gravity of area under the parabola and limited by ordinates at the leading and trailing edges.

$$t=\frac{\frac{(1+Z)}{3}\,\frac{(1+Z)^3}{4P}\times 0.25-\frac{Z}{3}\times\frac{Z^2}{4P}\,\frac{(4+Z)}{4}}{\frac{(1+Z)}{3}\,\frac{(1+Z)^2}{4P}-\frac{Z}{3}\times\frac{Z^2}{4P}}$$

$$t=\frac{6Z^2+4Z+1}{4(3Z^2+3Z+1)}$$

The curve shown in figure 2 is the graphical representation of the equation within the extreme limits of the position of the center of pressure in high incidence.

DETERMINATION OF RIB SPACING.

Application of a method to determine maximum rib spacing. From British Report 1912–1913 No. 84, reviewed in McCook Field Report, R. D. M. No. 277.

Let t=stress per foot length in the transverse fiber.
P=pressure per unit area on fabric.
D=distance between ribs in feet.
e=strain in fibers due to fabric bulging between the ribs under the pressure.

$$t=PD\sqrt{\frac{1}{24e}}$$

The problem is then to obtain a value of "t" at which the strain in the filler of the fabric determined from the formula is equal to the strain secured from the stress-strain diagram of a test specimen of the fabric.

For example, assume the following conditions:
Load factor in high incidence for wing=6.5.
Load factor in high incidence for fabric=19.5.
Normal wing loading in pounds per square foot=10.
Wing load with load factor of 19.5=195 pounds per square foot.
Spacing of ribs=30 inches.
Mercerized cotton airplane fabric (grade B) Spec. No. 16005–A.

The load factor for the fabric should be three times the load factor for the wing structure, since the local stresses in the fabric at a high angle of incidence corresponding to that occurring in flattening out after a dive have been shown to be about three times the average load. The severest stresses occur in a fabric under this condition.

$$t=195\times\frac{30}{12}\sqrt{\frac{1}{24e}}=\frac{98.6}{\sqrt{e}}$$

$$t^2=\frac{9940}{e} \text{ or } e=\frac{9940}{t^2}$$

t	120 lbs./ft.	240 lbs./ft.	360 lbs./ft.	480 lbs./ft.	
e	0.0267	0.0334	0.0383	0.0435	From stress-strain diagram for filler.
e	.690	.172	.0767	.0432	From formula $e=\frac{9940}{t^2}$

The specifications call for 875 pounds per foot of width for this fabric, so that theoretically the fabric is almost twice as strong as necessary. The effect of tears and defects introduce stresses which it is impossible to calculate, and as a result this method of analysis of fabric stresses should be used merely as a guide.

TYPICAL DESIGN OF RIB.

To illustrate the application of the principles of rib design, the complete design of the ribs for the CO–2 corps observation airplane will be worked out.

DESIGN DATA.

Type: Biplane.

Gross weight including supercharger=4,760 pounds.

Weight of wind structure assumed=540 pounds, corresponding to 1.15 pounds per square foot.

Area upper wing=262.5 square feet.

Area lower wing=206.5 square feet.

Total area=469 square feet.

Chord=75 inches.

Wing section: U. S. A. 27.

Spar location:

Front spar 8¼ inches from leading edge.

Rear spar 51¾ inches from leading edge.

Load factors for wing structure: High incidence=6.5; low incidence=4.5; reversed flight=3.0.

HIGH INCIDENCE.

Area of upper wing=262.5 square feet.

Effective area lower wing=$0.90\times206.5=185.9$ square feet.

Effective area wings=448.4 square feet.

Unit load on upper wing=$\frac{4760}{448.4}=10.62$ pounds per square foot gross.

Unit load on lower wing=$0.90\times10.62=9.56$ pounds per square foot gross.

Net unit load on upper wing=$10.62-1.15=9.47$ pounds per square foot.

Net unit load on lower wing=$9.56-1.15=8.41$ pounds per square foot.

Center of pressure location at 0.274 chord.

Load factor for ribs=$6.5+0.5=7.0$.

LOW INCIDENCE.

Area of upper wing=262.5 square feet.

Effective area of lower wing=$0.95\times206.5=196$ square feet.

Effective area of wings=458.5 square feet.

Unit load on upper wing=$\frac{4760}{458.5}=10.37$ pounds per square foot gross.

Unit load on lower wing=$0.95\times10.37=9.86$ pounds per square foot gross.

Net unit load on upper wing=$10.37-1.15=9.22$ pounds per square foot.

Net unit load on lower wing=$9.86-1.15=8.71$ pounds per square foot.

The rib spacing outside of the slip stream is taken as 15 inches and within the slip stream as 9 inches.

RIB LOADING.

(a) High incidence: Load per rib=$\frac{75}{12}\times\frac{15}{12}\times9.47\times7=517$ pounds.

(b) Case A loading (see pp. 1 and 2): Load per rib=$\frac{75}{12}\times\frac{15}{12}\times9.22\times6=432$ pounds.

The load factor for Case A is the average between the load factors for high and low incidence plus one-half of a load factor.

DISTRIBUTION OF LOAD BETWEEN SPARS.

High incidence:

Front spar $\frac{(51.75-20.75)}{43.5}\times517$	=367
Rear spar	=150
	517

Case A loading:

Front spar $\frac{(51.75-33.40)}{43.5}\times432$	=182
Rear spar	=250
	432

LOAD DISTRIBUTION ALONG THE CHORD.

High incidence:

From figure 2 for c. p.=0.274; Z=0.10 chord=7.5 inches.

Area under parabola=$\frac{1}{3}\times82.5\times\frac{(82.5)^2}{4P}-\frac{1}{3}\times7.5\times\frac{\overline{7.5}^2}{4P}=517$ pounds P=90.6.

Equation of parabola of loading=$x^2=4\times90.6y$.

Ordinate at leading edge=$\frac{\overline{82.5}^2}{4\times90.6}=18.8$ pounds.

Ordinate and trailing edge=$\frac{\overline{7.5}^2}{4\times90.6}=0.155$ pounds.

CASE A LOADING.

$\frac{1}{2}\times75\times X=432$

$X=11.5$ pounds.

The apex of the triangular loading is assumed to be one-third the chord from the leading edge, which corresponds to a center of pressure of 0.445 chord.

FABRIC TENSION.

The fabric tension is assumed to be 4 pounds per linear inch measured parallel to the direction of the spars.

Thrust=$2\times15\times4=120$ pounds.

GENERAL DESCRIPTION OF RIBS.

Material: Duralumin.

Chord members: U-shaped.

Web members: Sheet duralumin bent to tubular shape except at ends, where they are slit back and riveted to flanges.

Diagonals adjacent to spars are continuous.

Type of truss: Pratt. See diagrammatic sketch, figure 8.

Single-riveted construction.

Table I gives the panel concentrations for the three loading conditions. Refer to figure 8.

TABLE I.

Panel point.	Panel concentration.		
	High incidence.	Case A.	Fabric tension.[1]
			Pounds.
a	28.0	0.56	120
b	62.3	5.62	
c	47.3	9.47	
d	69.8	25.5	
e	98.0	67.9	
f	76.4	95.95	
g	55.0	79.2	
h	35.0	58.2	
i	16.1	28.0	
j	9.6	19.5	
k	10.5	20.8	
l	7.3	18.0	
m	1.7	3.60	120
Total	517.0	432.0	

[1] The loads due to fabric tension are applied at the leading and trailing edge; and are applied along the line connecting these points.

The stresses were solved graphically with the results shown in Table II.

TABLE II.—*Tabulation of direct stresses.*

Chord.			Web.		
Member.	High incidence.[1]	Case A.	Member.	High incidence.[1]	Case A.
		Pounds.			*Pounds.*
B-1	− 70	− 35	1-2	+ 22	+ 22
C-3	−103	− 23	2-3	+ 62	− 5
E-6	− 70	+ 4	6-7	+262	+220
F-8	+118	+161	7-8	− 75	−108
G-10	+205	+261	8-9	+115	+137
H-13		+137	9-10	− 15	− 43
I-15		− 62	10-11		− 14
K-18		− 89	11-12		− 38
L-20		− 51	12-13		+153
M-22		− 32	13-14		−110
N-22		− 73	14-15		+264
O-21		− 73	18-19		+ 45
P-19		− 54	19-20		− 18
R-14		−240	20-21		+ 23
S-12	−318	−354	21-22		− 4
T-11	−318	−353			
U-9	−324	−365			
V-7	−240	−263			
X-2	− 71	− 80			
Y-1	− 76	− 83			

[1] The stress diagram for the high incidence condition was discontinued at a point at which the high incidence loading no longer limited the design.

BENDING MOMENTS IN CHORDS.

Case A loading gives the most severe bending stresses in the chord members between spars. The analysis was first made on the assumption that the entire load was carried by the lower chord. Figure 9 is the bending moment diagram for the lower chord. To provide for the contingency of the attachment of the fabric to the upper chord, and also to provide for the bending stresses in the upper chord due to reverse flight, the upper chord should be designed for about 70 per cent of the bending moment in the lower chord.

DESIGN.

TYPICAL DESIGN OF WEB MEMBER.

Member 6-7:

Stress in direct flight, Case A loading=+220 pounds.

Stress in direct flight, high incidence loading=+262 pounds.

Stress in reversed flight loading=−131 pounds.

Length=11.7 inches.

Assume $\frac{3}{8}$ inch diameter by 0.014-inch gauge.

Area=0.01585 square inch.

$\rho=0.1282$.

$L/\rho=91.5$.

f allowable=11,700 pounds per square inch.

$f \text{ actual}=\frac{131}{0.01585}=3{,}250$ pounds per square inch.

The designs of the web members are tabulated in Table III. A liberal margin of safety is allowed because the resistance of duralumin to fatigue has not been investigated thoroughly.

The horizontal rivet at the extremity of each web member should be designed like a bridge pin to resist shearing and bearing stresses. The rivet must have sufficient bearing on the vertical web of the flanges so that the allowable bearing value of the material will not be exceeded. Tables IV and V give the allowable values of one-sixteenth inch diameter, three thirty-seconds inch diameter, one-eighth inch diameter, five thirty-seconds inch diameter, and three-sixteenths inch diameter duralumin and soft-steel rivets in single and double shear. The allowable bearing values of these rivets on commercial plates are also given.

Sufficient provision should be made to transmit the shear to the spars. See figures 6 and 7.

TABLE III.—*Design of web members.*

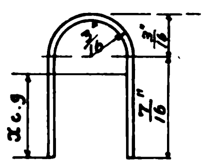
Member.	Limiting stress.	Length (inches).	Area (inch).[2]	I (inch).[4]	ρ (inch).	$L/S\rho$	Actual stress.	Allowable stress.	Section.
1–2		4.1							Material duralumin.
2–3	{+62 H. I. / −31 R. F.}	6.0							
6–7	{+262 H. I. / −131 R. F}	11.7	0.01585	0.000264	0.1282	91.5	8,250	11,700	$\frac{3}{8}$-inch diameter by 0.014-inch gauge.
7–8	−108 A	7.9	.01310	.000146	.1057	74.5	8,250	16,800	$\frac{5}{16}$-inch diameter by 0.014-inch gauge.
8–9	{+137 A / −58 R. F.}	11.6	.01310	.000146	.1057	110	4,425	8,200	$\frac{5}{16}$-inch diameter by 0.014 inch gauge.
9–10	−43 A	7.5	.01035	.0000725	.0837	89.5	4,150	12,200	$\frac{1}{4}$-inch diameter by 0.014-inch gauge.
10–11	−14 A	11.4							$\frac{1}{4}$-inch diameter by 0.014-inch gauge.
11–12	−38 A	7.1							$\frac{1}{4}$-inch diameter by 0.014-inch gauge.
12–13	+153 A	11.1							$\frac{5}{16}$-inch diameter by 0.014-inch gauge.
13–14	−110 A	6.6	.01310	.000146	.1057	62.5	8,400	19,800	$\frac{5}{16}$-inch diameter by 0.014-inch gauge.
14–15	+264 A	10.2	{[1] .01585 / [2] .01235}				21,400	55,000	$\frac{3}{8}$-inch diameterby 0.014-inch gauge.
18–19	+45 A	7.4							$\frac{5}{16}$-inch diameter by 0.014-inch gauge.
19–20	−18 A	4.4							$\frac{1}{4}$-inch diameter by 0.014-inch gauge.
20–21	+23 A	6.0							$\frac{1}{4}$-inch diameter by 0.014-inch gauge.
21–22	−4 A	3.1							$\frac{1}{4}$-inch diameter by 0.014-inch gauge.

[1] Gross. [2] Net.

H. I.=high incidence loading.
R. F.=reversed flight loading.
A=Case A loading (intermediate between high and low incidence).

FLANGE DESIGN.

Member U-9 is the greatest stressed member of the lower chord, and the design of the member will be carried through.



0.028 gage

Direct stress Case A loading=−365 pounds.
Bending moment center of panel=−25.4 inch pounds.
Bending moment at panel points=+53.9 inch pounds. and+69.7 inch pounds.

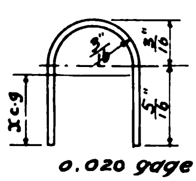
Properties of section:
- Gross area=0.0398 square inch.
- Net area=0.0328 square inch.
- $x_{c.g.}$=0.367 inch.
- $I_{c.g.}$=0.00161 inch.[4]
- ρ=0.201 inch.

$$f_c=\frac{365}{0.0328}=11{,}140 \text{ pounds per square inch.}$$

$$f_b=\frac{69.7\times0.367}{0.00161}=\frac{15{,}850 \text{ pounds per square inch.}}{26{,}990 \text{ pounds per square inch.}}$$

$$f\ \text{allowable}=\frac{15.850}{26{,}990}(55000-27000)+27000=43{,}450 \text{ pounds per square inch.}$$

Member G−10 is the greatest stressed member in the upper chord.
Direct stress=+261 pounds Case A.
Bending moment center of panel=−27.1 inch pounds.
Bending moment at panel points=+48.8 or 40.6 inch pounds.



0.020 gage

Properties of section:
- Gross area=0.02365 square inch.
- Net area=0.01865 square inch.
- $x_{c.g.}$=0.2832 inch.
- $I_{c.g.}$=0.000562 inch.[4]
- ρ=0.154 inch.

$$f_c=\frac{261}{0.01865}=14{,}000 \text{ pounds per square inch.}$$

$$f_b=\frac{48.8\times0.2832}{0.000562}=\frac{24{,}600 \text{ pounds per square inch.}}{38{,}600 \text{ pounds per square inch.}}$$

f allowable=55,000 pounds per square inch.

The lower chord and upper chord were designed uniform throughout in order to simplify the construction.

STRENGTH-WEIGHT RATIO OF RIBS.

The strength-weight ratios of several wooden ribs are plotted against chord lengths in figure 10. It should be particularly noted that the strength in each case is the test load at failure for Case A loading, in which the center of pressure is from 41.6 to 44.5 per cent back from the leading edge. For a well-designed rib the strength-weight ratio will be considerably higher for high incidence loading.

The curve drawn indicates the efficiency that can be expected in the design of ribs of various chords. The curve is almost straight from 90 to 180. The decrease in the slope to the left of 90 is due to the fact that limiting sizes of web and chord members are reached below which it is undesirable to reduce the sections. With chord lengths under 100 inches it is difficult to attain as great an efficiency with metal ribs as with wooden ribs because the gauge of the metal is limited by local buckling stresses. For duralumin it is recommended that the minimum gauge for the upper chord should be 0.020, lower chord 0.028, and web members 0.014. When using channel or U-sections the ratio of the length of the unsupported outstanding leg to the thickness of the material should not exceed 16.

TABLE IV.—*Rivets—Shearing and bearing values based on ultimate stresses.*

[Values in pounds; dimensions in inches.]

	Soft steel rivets and steel plate.					
Shear.	Rivet diameter	1/16	3/32	1/8	5/32	3/16
	Single shear per rivet	108	241	431	672	964
	Double shear per rivet	216	482	862	1,344	1,928
Bearing.	#24 B. W. G	137	206	274	344	412
	#22 B. W. G	175	263	350	437	526
	1/32	195	293	390	488	586
	#20 B. W. G	219	328	438	547	656
	#18 B. W. G	306	459	612	767	918
	#16 B. W. G	407	609	814	1,015	1,218
	1/16 in	390	586	780	976	1,172
	3/32	587	878	1,174	1,460	1,756
	1/8	780	1,172	1,560	1,952	2,344

Based on steel:

Allowable shearing stress rivet steel=35,000 pounds per square inch.

Allowable bearing stress of steel plate=100,000 pounds per square inch.

TABLE V.—*Rivets—Shearing and bearing values based on ultimate stresses.*

[Values in pounds; dimensions in inches.]

	Duralumin rivets and duralumin plate.					
Shear.	Rivet diameter	1/16	3/32	1/8	5/32	3/16
	Single shear per rivet	90	201	359	560	803
	Double shear per rivet	180	402	718	1,120	1,606
Bearing.	0.014	78	118	156	197	236
	0.020	112	169	224	281	338
	0.028	157	237	314	394	474
	0.032	180	271	360	450	542
	0.064	360	542	720	900	1,084
	3/32	527	792	1,054	1,317	1,584
	1/8	702	1,056	1,404	1,760	2,112

Based on duralumin:

Allowable shearing stress=30,000 pounds per square inch.

Allowable bearing stress=90,000 pounds per square inch.

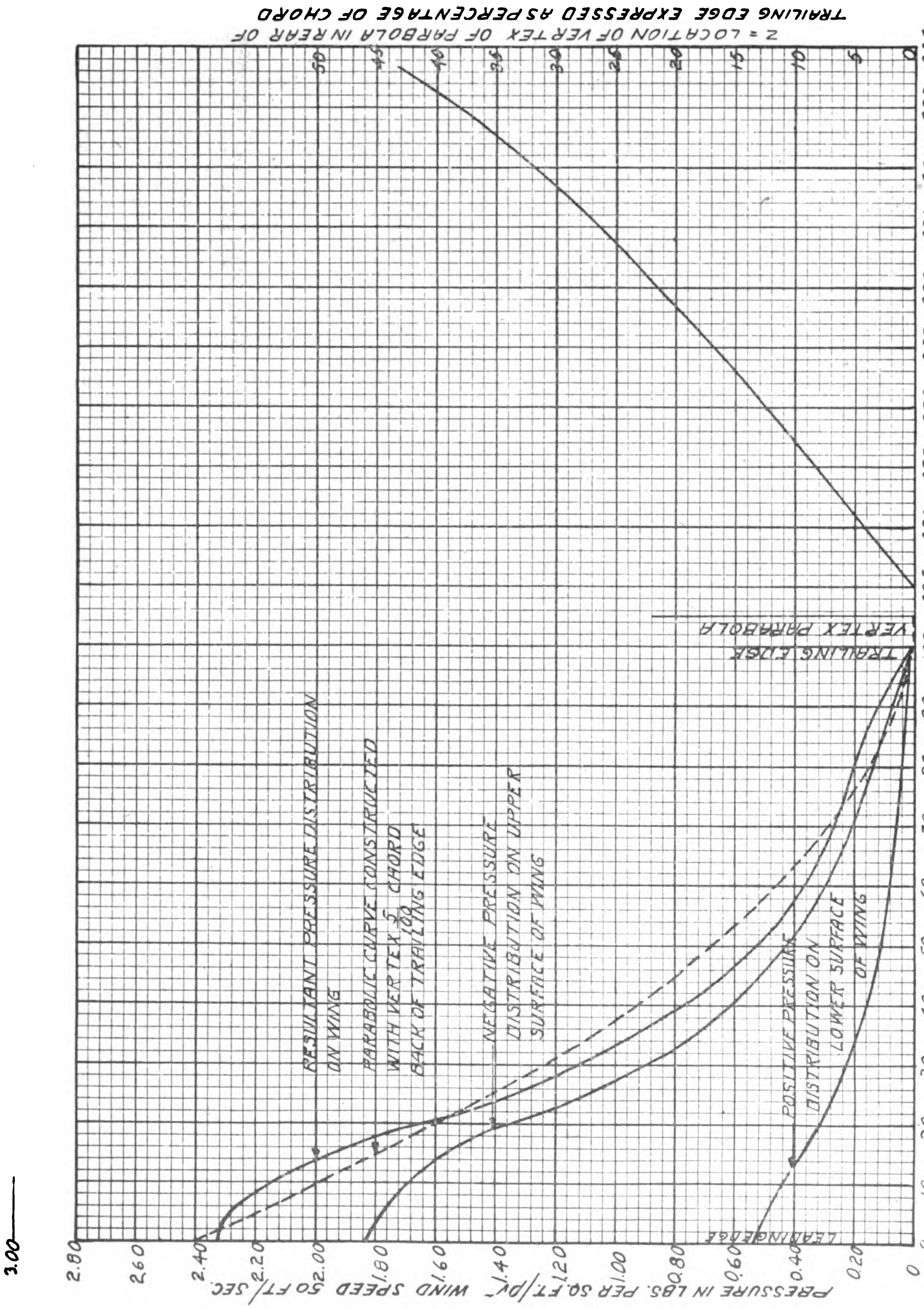


Fig. 1.—Per cent chord from leading edge.

Fig. 2.—Location of c. p. in rear of leading edge.

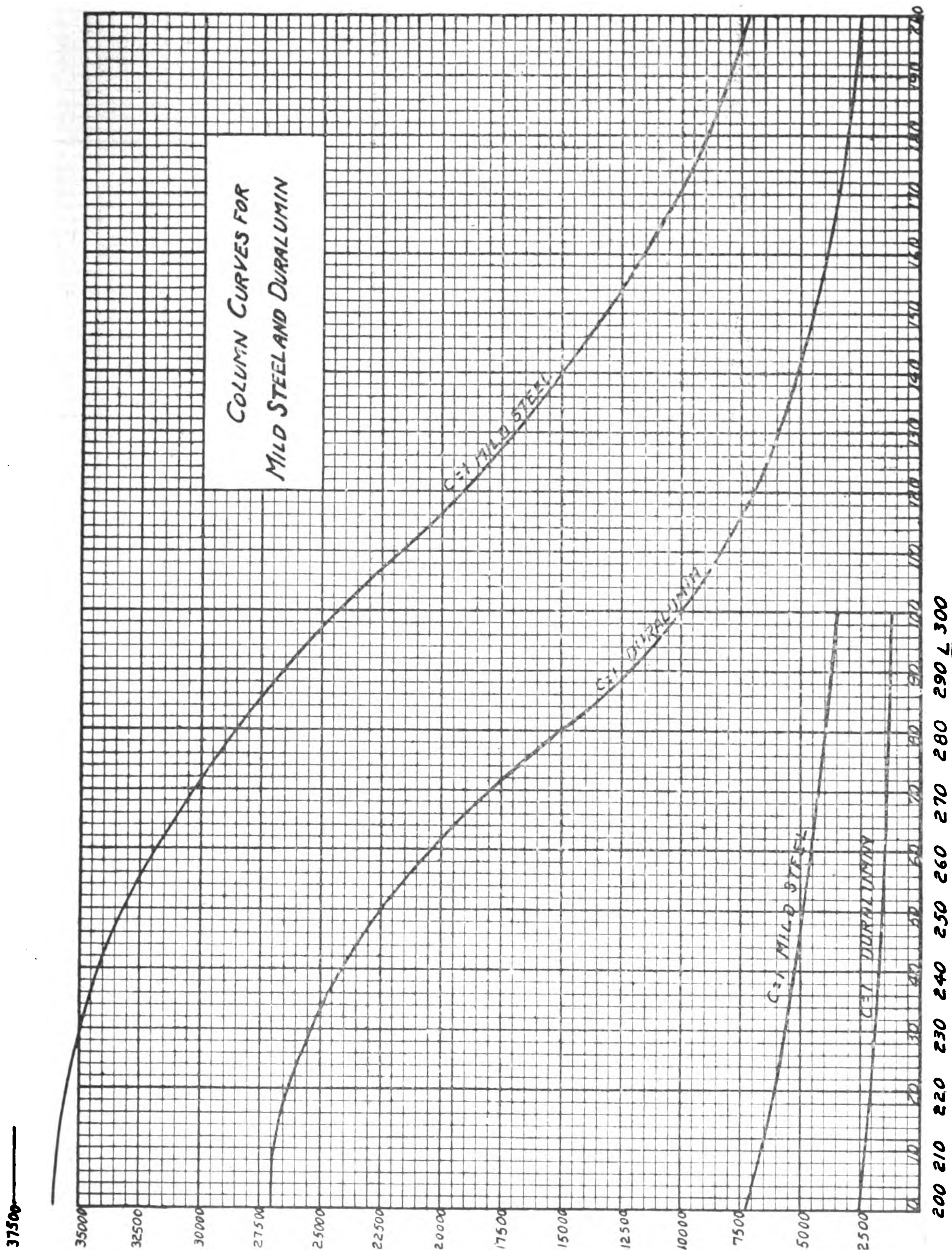
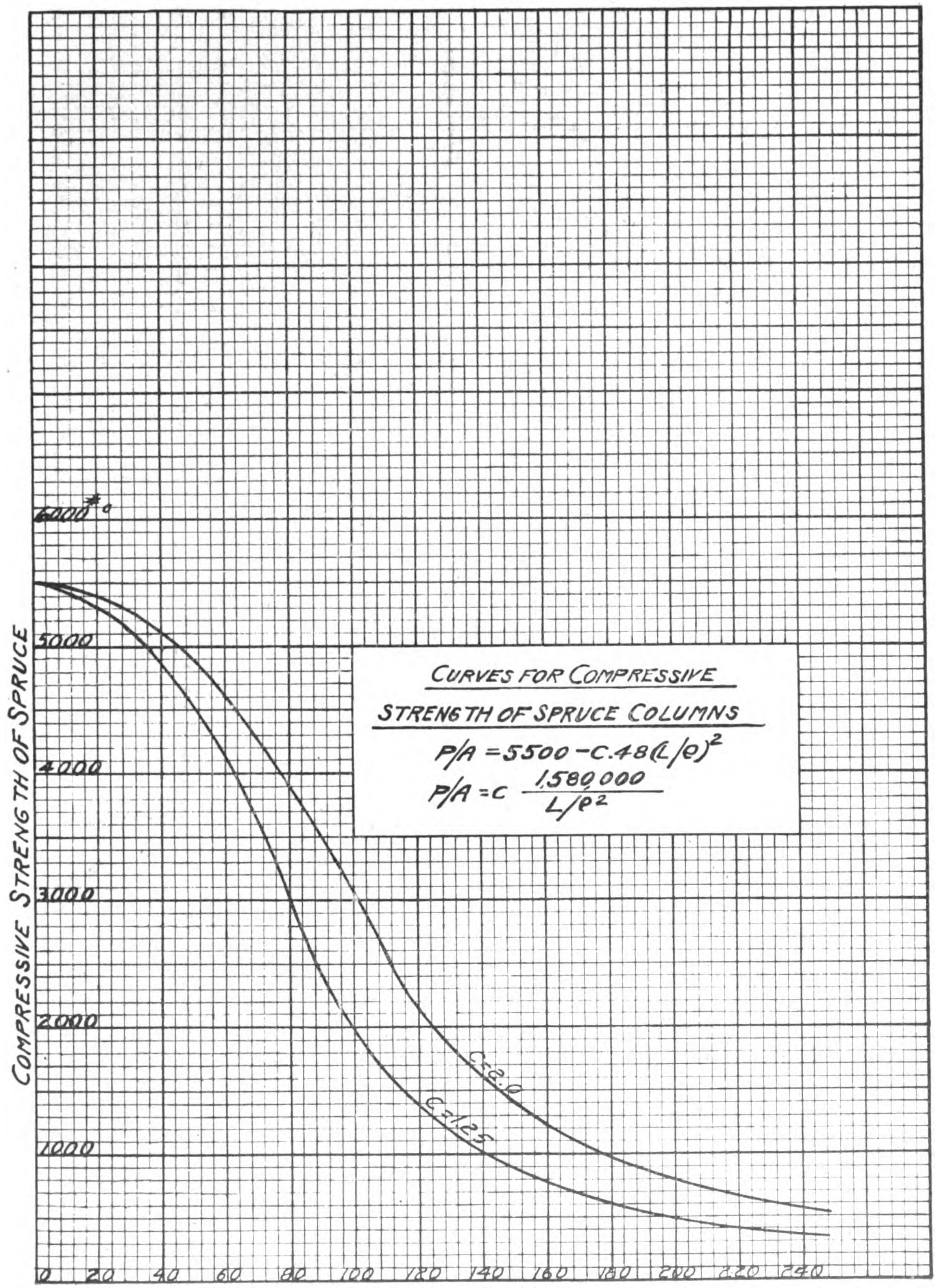


FIG. 3.—Allowable unit stresses in compression.



CURVES FOR COMPRESSIVE
STRENGTH OF SPRUCE COLUMNS
P/A = 5500 − C .48(L/e)²
P/A = C 1,580,000 / L/e²
COMPRESSIVE STRENGTH OF SPRUCE
6000#□
5000
4000
3000
2000
1000
0 20 40 60 80 100 120 140 160 180 200 220 240
C=2.0
C=1.25

FIG. 4.

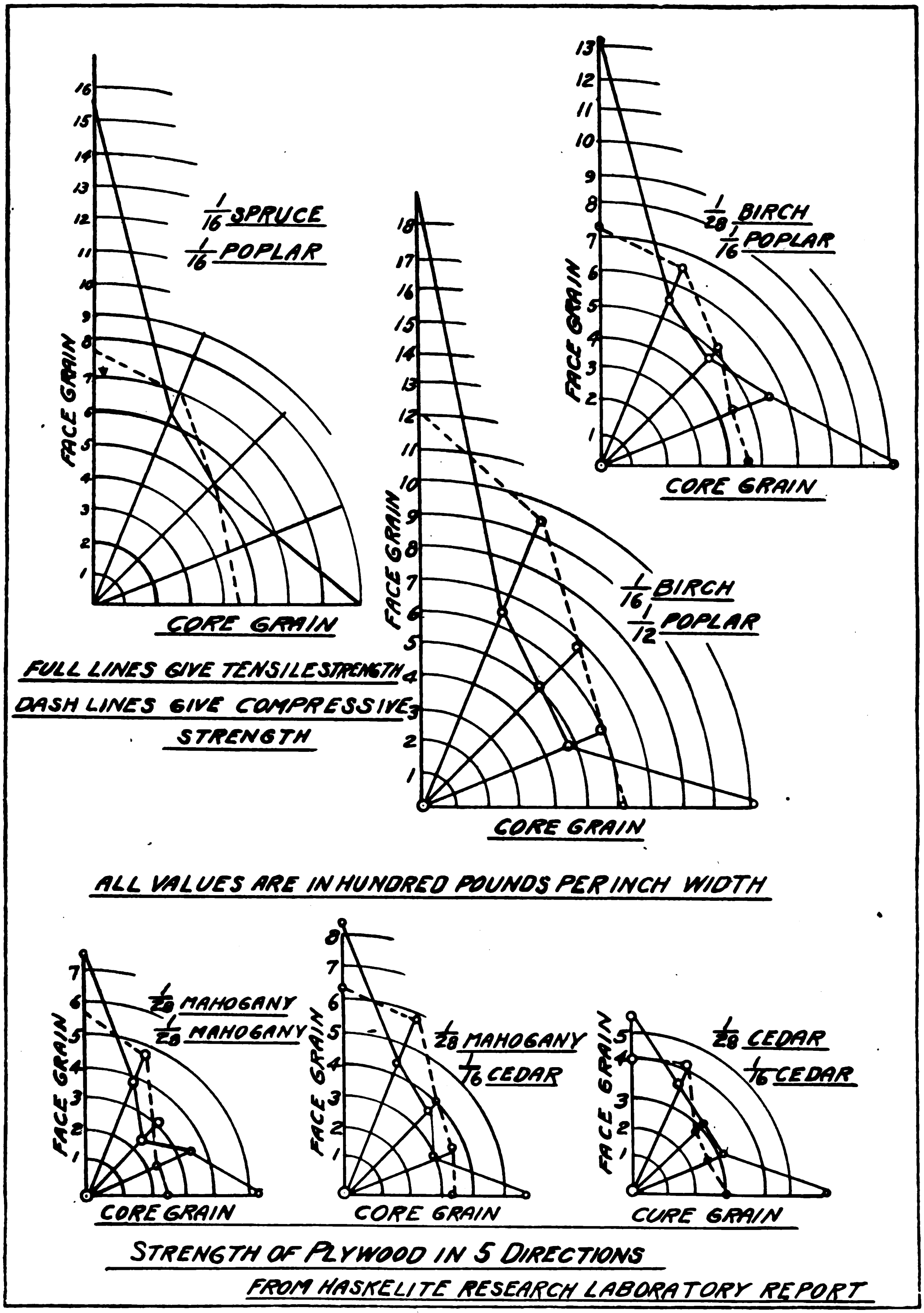

1/16 SPRUCE
1/16 POPLAR
FACE GRAIN
CORE GRAIN
FULL LINES GIVE TENSILE STRENGTH
DASH LINES GIVE COMPRESSIVE STRENGTH
1/28 BIRCH
1/16 POPLAR
1/16 BIRCH
1/12 POPLAR
ALL VALUES ARE IN HUNDRED POUNDS PER INCH WIDTH
1/28 MAHOGANY
1/28 MAHOGANY
1/28 MAHOGANY
1/16 CEDAR
1/28 CEDAR
1/16 CEDAR
CURE GRAIN
STRENGTH OF PLYWOOD IN 5 DIRECTIONS
FROM HASKELITE RESEARCH LABORATORY REPORT

FIG. 5.

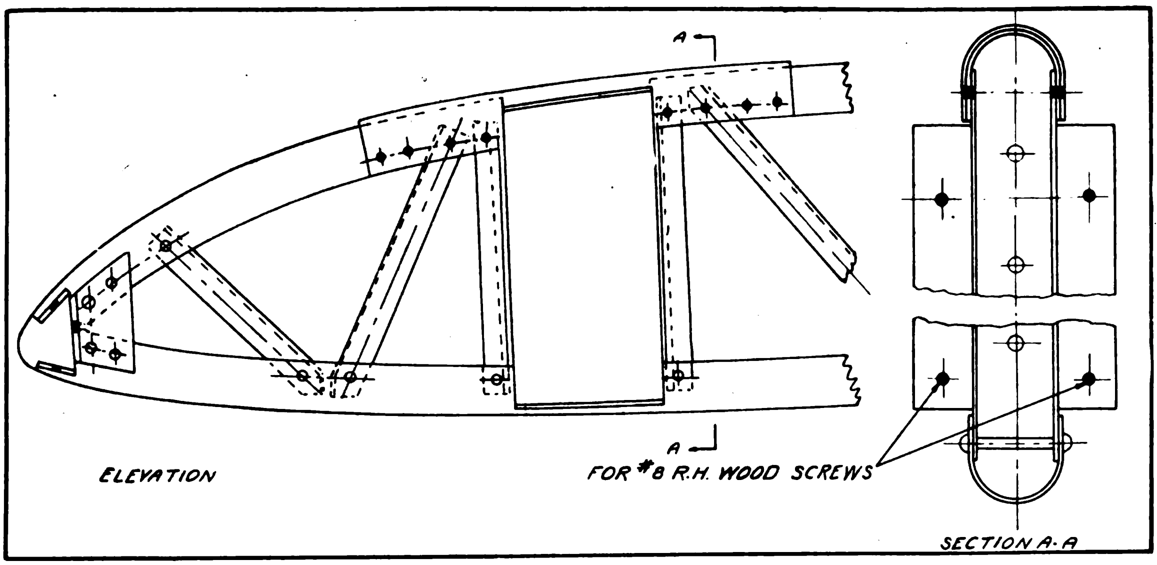


FIG. 6.—Attachment of duralumin rib to a wooden spar.

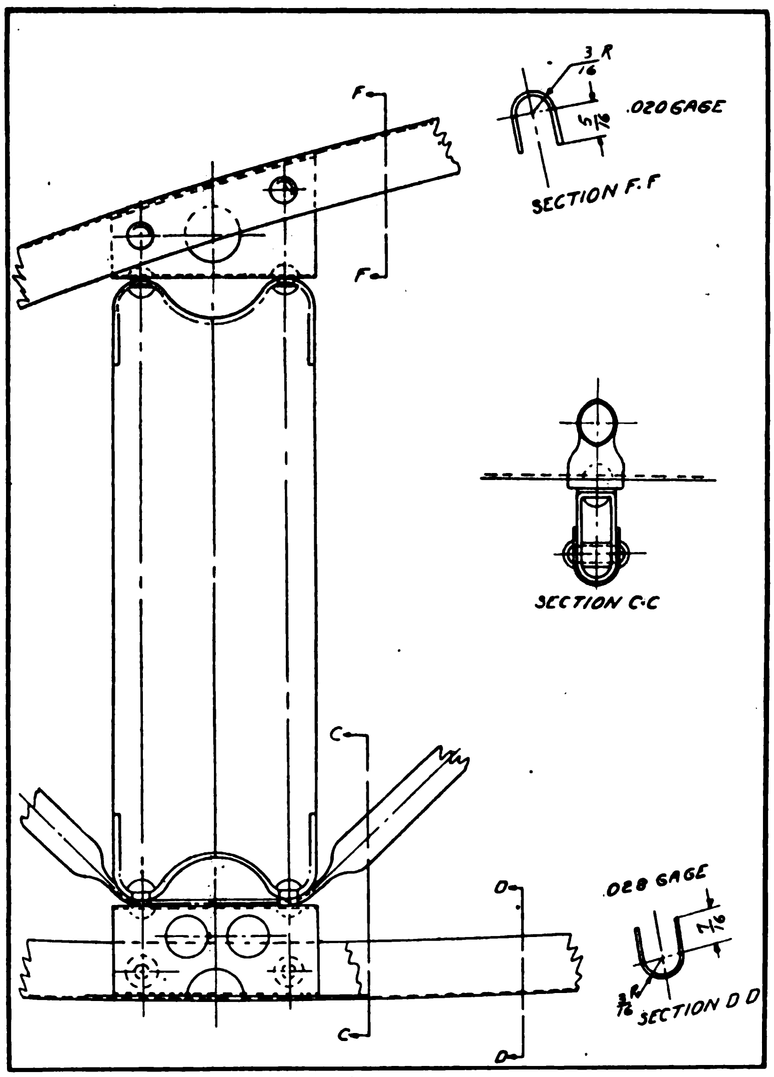


FIG. 7.—Connection of duralumin rib to duralumin spar.

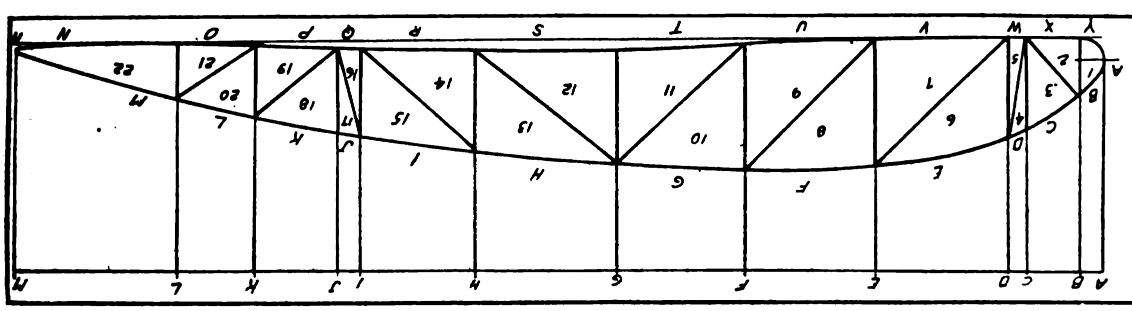


FIG. 8.—Key diagram for rib stresses to be used in conjunction with stress tables.

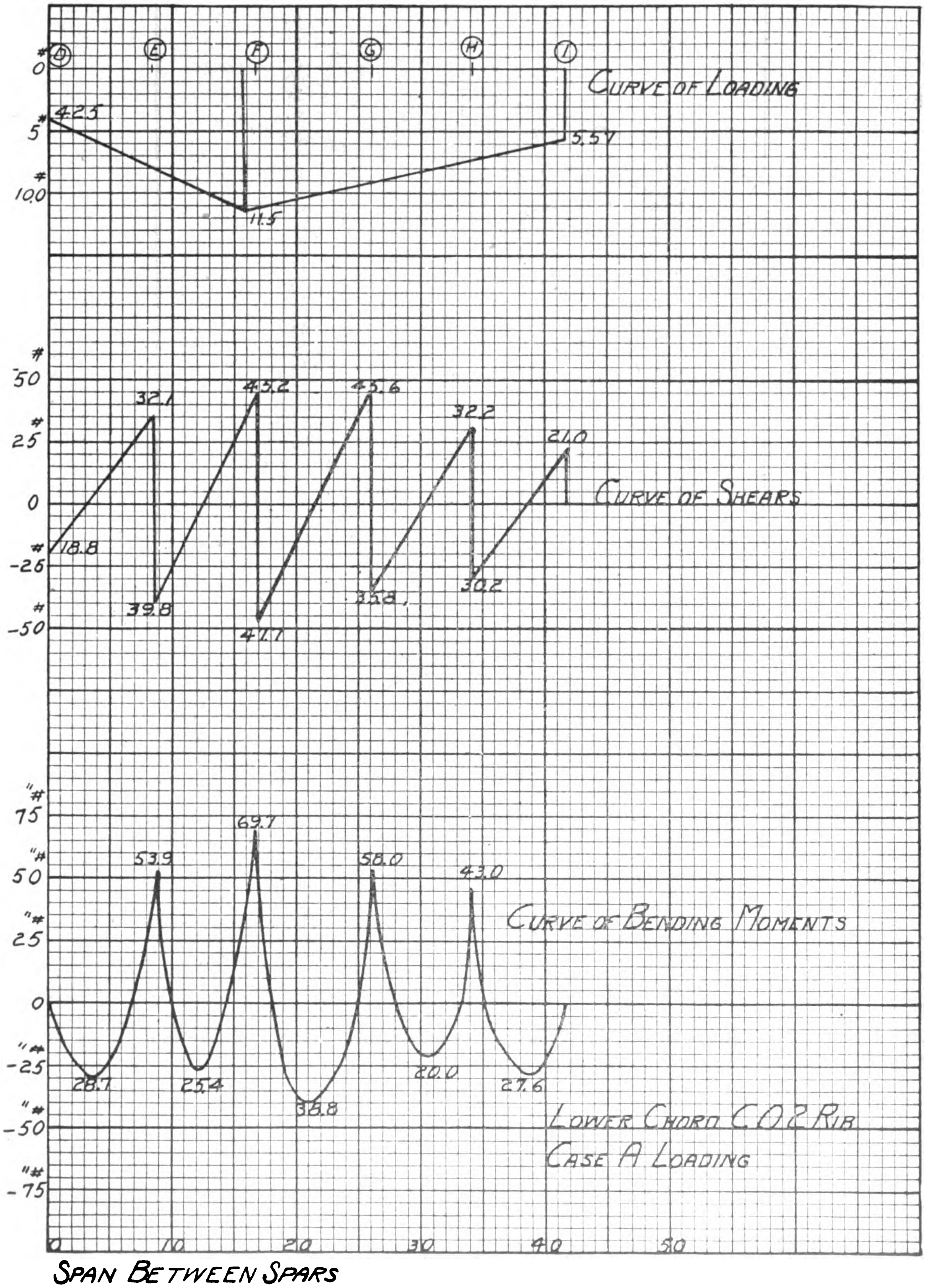
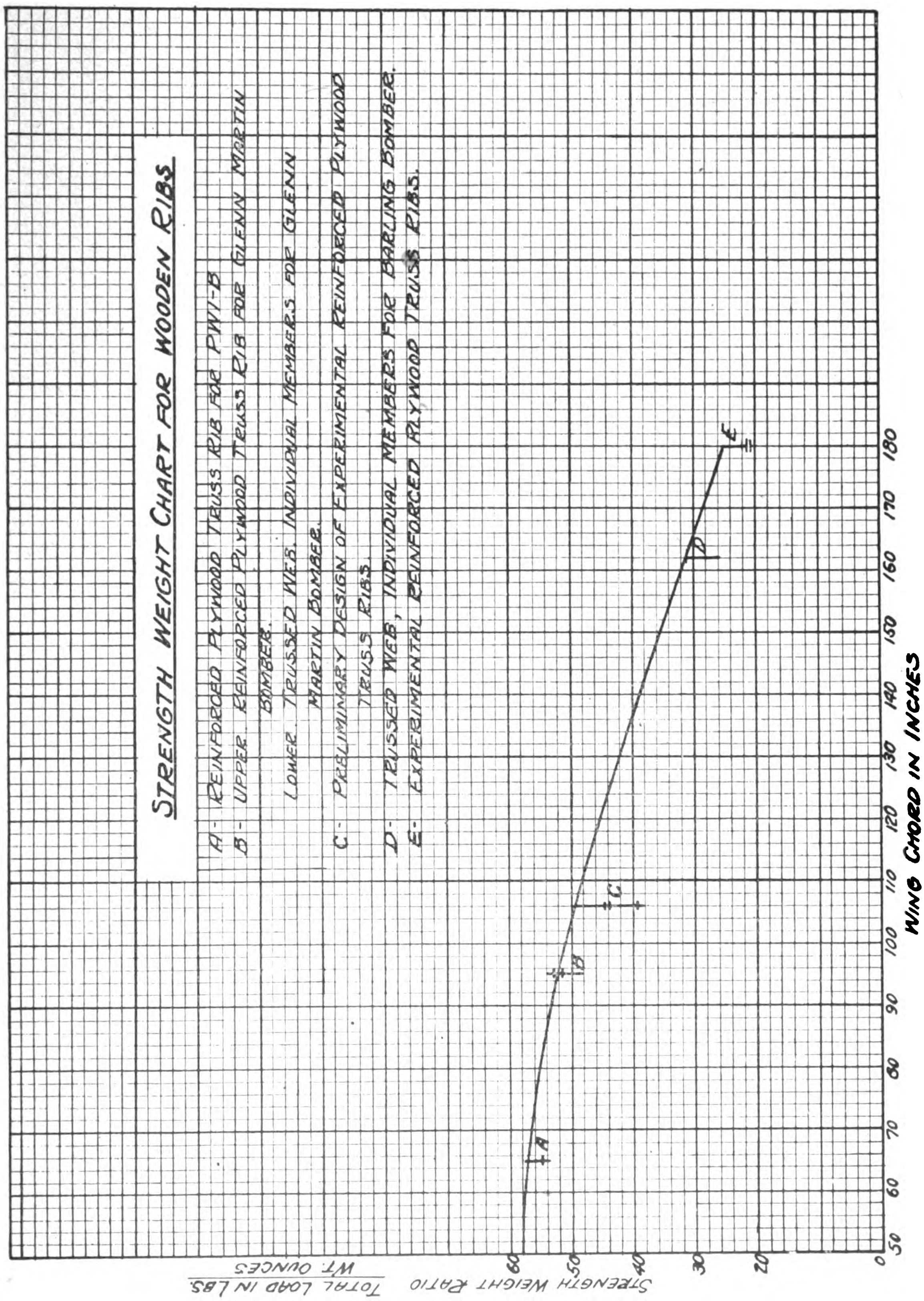

D
E
F
G
H
I
Curve of Loading
4.25
5.57
11.5
0
5
10.0
Curve of Shears
32.1
43.2
43.6
32.2
21.0
18.8
39.8
47.7
35.8
30.2
50
25
0
-25
-50
Curve of Bending Moments
53.9
69.7
58.0
43.0
28.7
25.4
38.8
20.0
27.6
75
50
25
0
-25
-50
-75
Lower Chord C.O.2 Rib
Case A Loading
0
10
20
30
40
50
Span Between Spars

Fig. 9.



STRENGTH WEIGHT CHART FOR WOODEN RIBS
A - REINFORCED PLYWOOD TRUSS RIB FOR PW1-B
B - UPPER REINFORCED PLYWOOD TRUSS RIB FOR GLENN MARTIN BOMBER.
LOWER TRUSSED WEB. INDIVIDUAL MEMBERS FOR GLENN MARTIN BOMBER.
C - PRELIMINARY DESIGN OF EXPERIMENTAL REINFORCED PLYWOOD TRUSS RIBS.
D - TRUSSED WEB, INDIVIDUAL MEMBERS FOR BARLING BOMBER.
E - EXPERIMENTAL REINFORCED PLYWOOD TRUSS RIBS.
A
B
C
D
E
50
60
70
80
90
100
110
120
130
140
150
160
170
180
WING CHORD IN INCHES
0
20
30
40
50
60
STRENGTH WEIGHT RATIO
TOTAL LOAD IN LBS. / WT. OUNCES

FIG. 10.

File D 52.331/37 *McCOOK FIELD REPORT, SERIAL No. 1737*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV March 15, 1922 No. 313

REINFORCED PLY-WOOD WEB SPARS

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
May 21, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INDEX.

REINFORCED PLY-WOOD WEB SPARS.

The success of reinforced ply-wood construction in the design of large ribs suggested its application to the construction of large spars such as are used in internally braced construction with thick wing sections.

The following development work was conducted to determine the adaptability of reinforced ply-wood web construction to spars, and also to compare the relative merits of the solid-web and trussed-web types.

Two series of designs and tests were made on each type of construction. The first test emphasized the necessity of certain design features, and the necessity of securing good gluing. The second series of designs incorporated the results of our experience with the first series of designs, and is thought to provide an excellent basis of comparison between the solid-web and trussed-web construction.

FIRST SERIES OF TESTS.

Type A—$\frac{3}{16}$-inch ply-wood truss web reinforced.
Type B—$\frac{1}{8}$-inch ply-wood truss web reinforced.
Type C—$\frac{3}{16}$-inch solid ply-wood web unreinforced.
Type D—$\frac{1}{8}$-inch solid ply-wood web unreinforced.
Type E—$\frac{3}{32}$-inch solid ply-wood web reinforced with vertical stiffener strips.

SECOND SERIES OF TESTS.

Type A—$\frac{3}{32}$-inch solid ply-wood web reinforced with vertical stiffener strips. (See fig. 2.)

Type B—$\frac{3}{16}$-inch ply-wood truss web reinforced. (See fig. 1.)

The spars were supported at the ends and loaded with concentrated loads at the third points. The method of testing is shown clearly in figures 3 and 4.

Tables 1 and 2 are the test results of the first and second series of designs, respectively.

DISCUSSION OF FIRST SERIES OF TESTS.

The gluing on the first series of spars tested was unsatisfactory, and failure occurred in the gluing surfaces before the strength of the spars was developed. The spars were restrained laterally at the ends, quarter points, and center. The spars lacked lateral rigidity even when restrained as noted.

DISCUSSION OF SECOND SERIES OF TESTS.

The gluing on the second series of spars tested was excellent, and no failures could be attributed to faulty gluing. The webs of the solid-web type started to buckle when approximately 40 per cent of the load causing failure was applied. This buckling tendency was most pronounced midway between the load and the support. The end stiffening detail of the spars was found to be inadequate, as there was not sufficient provision made for transmitting the end shear to the supports. The spars were restrained laterally at the ends, quarter points, and center in three cases, and in the fourth case the lateral guides at the quarter points were removed. There was no tendency whatever of any of the spars tested to buckle laterally, and the removal of the lateral supports at the quarter points had no appreciable effect on the strength of the spars.

TABLE 1.—*Results of tests on reinforced ply-wood web spars (series 1).*

Type.	Weight.	Length.	Deflection per total load.[1]									Per cent designed load at failure.	Nature of failure.
			1,120	1,680	2,240	2,800	3,360	3,920	4,480	5,040	5,600		
	Lbs. oz.	*Ft. in.*											
A....	19 21	15 0	0.55	0.96	1.28	....	....	....	....	....	....	50	Failure in glue.
A....	20 0	15 0	.56	.86	....	....	....	....	....	....	....	40	Do.
B....	20 12	15 0	.60	....	....	....	....	....	....	....	....	30	Do.
C....	29 14	15 1	.42	.64	.84	1.06	1.26	1.46	1.64	....	....	90	Do.
C....	28 6	15 1	.50	.76	1.04	1.30	1.54	1.80	....	....	....	80	Do.
D....	25 4	15 1	.46	.70	.92	1.11	1.34	1.56	....	....	....	80	Do.
E....	23 12	15 1½	.44	.67	.86	1.08	....	....	....	....	....	60	Failure in lateral buckling.
E....	23 0	15 1½	.52	.82	1.06	1.22	1.30	....	....	....	....	70	Do.

[1] No deflection recorded at load causing failure.

TABLE 2.—*Results of tests on reinforced ply-wood truss spars (series 2).*

Type.	Weight.	Length.	Deflection per total load.[1]													Per cent designed load at failure.	Nature of failure
			1,100	1,650	2,200	2,750	3,025	3,300	3,573	3,850	4,125	4,400	4,675	4,950	5,225		
	Lbs. oz.	*Ft. in.*															
A....	25 0	15 1½	0.44	0.64	0.86	1.08	1.20	1.32	1.42	1.55	1.67	1.70	1.83	1.96	2.10	100	Bending failure in chord.
A....	24 8	15 8	.36	.61	.83	1.05	1.18	1.27	1.38	1.49	1.65	1.80	......	......	......	85	Do.
B....	23 14	15 4	.53	.81	1.09	1.31	(2)	1.50	......	......	......	......	......	......	......	65	Tension diagonal failed.
B....	22 14	15 4	(3)	(3)	(3)	(3)	1.75	......	......	......	......	......	......	......	......	60	Tension chord failed.

[1] The deflections were measured at the center of the spars.
[2] Omitted.
[3] Inaccurate records.

DISCUSSION OF FIRST SERIES OF DESIGNS.

The construction of the first series of spars tested was similar to the construction of the second series tested, the chief difference being that the flanges of the first series of spars were solid rectangular sections.

The design data is as follows:

All spars designed for two concentrated loads of 2,800 pounds at third points.

Modulus of rupture of spruce, 10,000 pounds per square inch.

Yield point in compression, 6,000 pounds per square inch.

Coefficient fixity web members:

2.50 in plane of truss.

1.75 normal to plane of truss.

Casin glue used.

Gluing strength taken as 1,000 pounds per square inch.

All members designed for 40 per cent reversal of stress in reversed flight.

The flanges of all spars were designed to resist the entire bending moment, and the web was designed to carry the shear. The allowable tensile and compressive strengths of ply wood when the applied load makes various angles with the direction of the grain were determined by charts constructed by the Haskelite Research Laboratory, which are reproduced in this report in figure 5. The shearing strength of ply wood was determined in accordance with the results of a series of tests made by the Forest Products Laboratory, which are incorporated in a report entitled "Shear strength of ply-wood webs," Project L-225-1. The principle that solid ply-wood webs are best adapted to resist shear when the direction of the face plies is at 45° with the axis of the beam was proven by tests recorded in the report cited. Therefore, the solid-web spars were designed in accordance with this principle.

Due to the defective gluing in the first series of spars, it is impossible to state the true strength of the designs tested. The tests indicated, however, that all spars tested were laterally unstable, and that further development work should take into consideration the widening of the flanges. The necessity of careful gluing was also evident.

The Pratt type of truss was used because the diagonal web members would be in tension in direct flight. The design of these members was limited by the reversed flight condition in which 40 per cent of the direct flight stresses were assumed, and of the opposite character. In the design of the web members direct stresses only were considered, and the effect of the eccentric application of the direct stress due to the lack of symmetry of the web section was ignored.

DISCUSSION OF SECOND SERIES OF DESIGNS.

The construction of the second series of spars tested is shown in figures 1 and 2.

The design data was the same as for the original spars with the following exceptions:

Coefficient of fixity of web members:

2.00 in plane of truss.

1.25 normal to plane of truss.

Loading, two concentrated loads of 2.750 pounds at the third points.

TRUSSED-WEB SPARS. (SEE FIG. 1.)

To secure lateral rigidity, the flanges were widened and the depth kept the same. In order to have sufficient gluing surface for the web members, the flanges were routed so that the sectional area of the flanges closely approximated the area of the original flanges.

The compression web members were designed by the method of secondary deflections to compensate for the eccentric application of the web stresses. This method of analysis had given excellent results in the design of a number of 15-foot reinforced ply-wood truss ribs and checked up closely in static test. This method of analysis is considered fully in McCook Field report, appendix to serial No. 1483.

SOLID-WEB SPARS.

The solid-web spars shown in figure 2 were designed as before. The flanges were designed to resist the entire bending moment and are exactly the same as for the trussed-web type. The web was made of $\frac{1}{16}$-inch spruce-popular ply wood reinforced with vertical stiffeners. The average vertical shearing stress at the designed load is much less than the shearing strength of the ply wood, but the consideration of stiffness is extremely important. This question of stiffness is taken up later in this report and a method of computing the size and spacing of web stiffeners is given. At the points of concentrated loading the stiffeners were designed to distribute the shearing stresses to the web, and at the points of support the stiffeners were designed to transmit the end shear.

RECOMMENDATIONS.

As the result of the test, it is strongly recommended that solid-web construction should be used in preference to the trussed-web construction. The solid-web type is more advantageous as regards strength-weight ratio, rigidity, ease of production, and economy of material.

It is recommended that the design should be made in accordance with the following principles:

(*a*) Relation between depth and width. To secure lateral rigidity the ratio between the depth of the spar and the width of the flanges should not exceed five.

(*b*) The flanges should be designed to resist the entire bending moment. The area of the flange sections required at any point is equal to the bending moment at the point in question divided by the product of the distance between centers of gravity of flanges and the allowable fiber stress in tension or compression. The yield point in compression should be used for the compression flange, and in general no reduction for column action will be necessary. The direct stress should be divided between the flanges in proportion to their respective sectional areas.

The depth of the flanges should provide sufficient gluing surface for the web. The depth required is found by computing the increase in longitudinal shear per inch near the point of maximum shear. There must be sufficient gluing surface to develop this stress. Experiment has proven that the strength of the gluing surface between two layers of wood is dependent upon the angle between the directions of the grain of the adjacent layers. When the directions of the grain in the adjacent layers are parallel the gluing strength is a maximum, and when the directions are

perpendicular the gluing strength is a minimum. For the former case the longitudinal shearing strength of the wood rather than the strength of the gluing surface will be the limiting condition, while in the latter case the strength of the gluing surface will govern. Also in the case of the solid-web spars in which the plies make an angle of 45° with the direction of the grain, the gluing strength will limit the design. It is recommended that the intensity of longitudinal shearing stress between the web and the flanges should not exceed 250 pounds per square inch. Further work should be conducted to determine the allowable values of the gluing strength when the direction of the grain of adjacent wood fibers varies from zero degrees to 90°.

To secure an economical flange design, it is advisable to rout the section, thus securing the necessary width and gluing surface with the minimum sectional area.

(c) The web should be designed to resist the shear. The average vertical shearing stresses are greatest near the supports. If the assumption that the web resists only the external shear is adhered to, the state of stress at any point in a vertical section of the web would be the same as that existing at the neutral axis of a solid beam. At any point in the web the planes of principal stress make an angle of 45° with the axis of the beam, and the intensities of the compressive and tensile stresses on these planes would each be equal to the intensity of the shearing stress on a vertical plane. Thin veneer (not ply wood) or laminated wood is not suitable to resist tensile stresses perpendicular to the direction of the grain. Ply wood, however, is very well adapted for this purpose, and it is one of the purposes of this report to discuss the qualities of ply wood which make it suitable for the webs of spars.

To secure maximum efficiency the ply wood should have the following qualities:

1. Maximum strength-weight ratio.
2. Tensile resistances equal when the applied load is normal and parallel to direction of the grain of the face plies.
3. Column bending resistance equal when the applied load is normal and parallel to direction of the grain of the face plies.
4. Maximum resistance to vertical shearing forces.

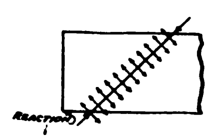
The Forest Products Laboratory conducted a series of important tests on the shearing strength of ply-wood webs, and recommended that the grain of the face plies should be at 45° with the axis of the spar. The variation in the maximum shearing stresses is shown in figure 6 for 3-ply ply wood of birch consisting of $\frac{1}{12}$-inch faces and $\frac{1}{8}$-inch core when the external shear is at various angles with the direction of the grain of the face plies. In our analysis it is assumed that the face plies are at 45° with the axis of the spar.

The column-bending, tensile, and shearing strengths of ply wood increase almost in direct proportion with the density of the material. It is not advisable, however, to use a dense material like birch for all plies, because the reduced total thickness of ply wood necessary is accompanied by a reduction in stiffness. The stiffness of the web is proportional to the unsupported distance between flanges divided by the thickness of the web. Birch, however, makes an excellent material for the faces because of its high strength and resistance to abrasion. It is advantageous to use a dense material like birch for the faces with a less dense material like poplar, spruce, or basswood for the core.

The tensile strength and column bending strength of ply wood when the applied load is parallel to the direction of the face plies decreases as the thickness of the core is increased, while the corresponding strengths perpendicular to the direction of the face plies increase. To secure uniform strength when using a core of poplar, spruce, or basswood in connection with dense face plies of birch, the core should be thickened. It is recommended that the core should constitute between 60 and 75 per cent of the total thickness of ply wood when using three plies. If more than three plies are used, the denser material should be thinner than the less dense core. The use of a wood such as poplar, spruce, or basswood of comparatively low density for the core makes it possible to secure a relatively thick ply wood for a given strength-weight ratio, and thus secure stiffness.

The tensile strength and column bending strength of ply wood when the applied load is parallel to the direction of the face plies decreases as the number of plies is increased, while the corresponding strengths perpendicular to the direction of the grain of the face plies increase. To secure uniform strength, the greatest number of plies possible should be used.

To illustrate the necessity of designing the web to resist column action, a portion of the web near the supports will be isolated and the forces acting on the section will be considered. (See sketch.) The section isolated is restrained laterally along its entire length by the tension in the web, and is subjected to compression along its axis. The ply wood must have sufficient strength to resist this load. It is interesting to note in this connection that both solid-web spars tested developed secondary failures due to this action. The average intensity of the shearing stress at failure, which also equals the intensity of the normal stresses on the principal planes, was 1,520 pounds per square inch, whereas the maximum allowable column bending modulus was 1,600 pounds per square inch, according to the Forest Products Laboratory report. The column bending moduli are equal to $P/A + My/I$ at failure, and may be taken as the criteria for column strength equivalent to the moduli of rupture for bending strength.



SUMMARY OF CHOICE OF WEB.

1. Use ply wood to secure uniform strength as nearly as possible.
2. Use as many plies as is consistent with economy of production.
3. Use face plies of high density with a core of relatively less density. Birch is recommended for the face plies in connection with a core of poplar, spruce, or basswood. When using three plies the core should constitute from 65 to 70 per cent of the total thickness of ply wood. The lower value represents the proportion necessary to secure about uniform tensile strength and the higher value represents the proportion necessary to secure uniform column bending strength. When using more than three plies, the relation between the total thickness of the lighter

wood to the denser wood should be slightly in excess of the inverse relation between the respective densities.

4. If the core and faces are the same kind of wood, the core should constitute 50 to 65 per cent of the total thickness of the ply wood when three plies are used. The lower limit will about equalize the tensile strengths, and the higher value will about equalize the column bending strengths when the applied load is parallel or normal to the direction of the grain of the face plies.

When the ply wood is proportioned as recommended, it will be unnecessary to design for column bending resistance and tensile resistance on diagonal planes at the points of maximum shear, because the vertical shearing stresses will limit the design.

A formula is derived below to determine the maximum allowable shearing stresses for plywood when the applied load makes an angle of 45° with the direction of the grain of the plies. The formula is based on the test results of 3-ply birch ply wood conducted by the Forest Products Laboratory. The shearing resistance of various woods are assumed to vary as their densities. This formula is approximate, but is the best indication of the shearing strength that can be obtained in the absence of experimental data.

$$f_s=\frac{a}{0.67}\times 5{,}000\times\frac{c}{100}+\frac{b}{0.67}\times 5{,}000\,\frac{(1-c)}{100}$$

Let a=density of core.

b=density of faces.

c=per cent or lighter wood of total thickness of ply wood.

$(1-c)$=per cent faces or denser material of total thickness of ply wood.

0.67=density of birch.

The following values of the allowable shearing stresses have been determined in accordance with the formula stated:

Number of plies.	Material.		Density.		Per cent total thickness.		f_s pounds per square inch.
	Face plies.	Core.	Face plies.	Core.	Face plies.	Core.	
3	Cherry	Basswood	0.56	0.42	40	60	3,550
3	do	Poplar	.56	.50	40	60	3,910
3	do	Spruce	.56	.42	40	60	3,550
3	do	Spanish cedar.	.56	.41	40	60	3,505
3	do	Mahogany	.56	.50	40	60	3,910
3	Birch or hard maple.	Basswood	.67	.42	40	60	3,880
3	do	Poplar	.67	.50	40	60	4,240
3	do	Spruce	.67	.42	40	60	3,880
3	do	Spanish cedar.	.67	.41	40	60	3,835
3	do	Mahogany	.67	.42	40	60	3,880

The spacing of intermediate web stiffeners is indeterminate, but a method of analysis is developed which is a modified form of the analysis upon which the spacing of vertical stirrups in reinforced concrete beams is based.

$$v=\frac{SQ}{I}$$

v=increase in longitudal shear per inch.

S=total external shear.

Q=statical moment of flange about horizontal axis of spar.

The approximations are made that the flanges have equal areas, that the moments of inertia of the flanges about their centers of gravity are negligible, and that the horizontal axis is halfway between the flanges.

$$v=\frac{S\times A\times h/2}{\frac{h^2A}{2}}=\frac{S}{h}$$

A=area of flange.

h=distance center to center of flanges.

The assumption is made that the vertical stiffeners develop in tension the longitudinal shearing stresses between two adjacent stiffeners.

$$F=\frac{VXd}{2}=\frac{Sd}{2h}$$

F=tensile strength of stiffeners.

$$d=\frac{2\,Fh}{S}$$

d=spacing of stiffeners.

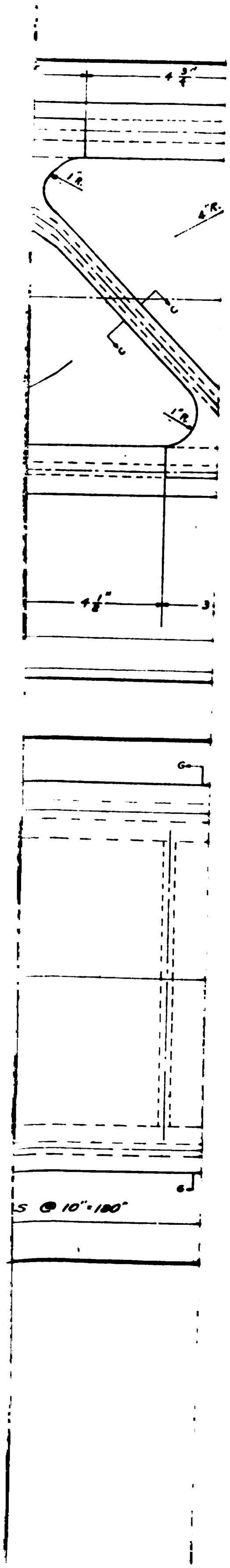
The spacing should not exceed the unsupported distance between flanges. Stiffeners should be used at the point of attachment of the ribs. In general, this condition will limit the spacing, since stiffeners will be required at the ribs and at a point intermediate between ribs.

Intermediate web stiffeners of rectangular section are advised, with the greatest dimension outstanding from the web of the spar. The outstanding dimension should be about ½ inch+1/30 the unsupported distance between flanges. The stiffeners should have a good bearing against the flanges.

At points of heavy load concentration and at the supports the stiffeners should be designed to transmit the load to the web in the first case, and from the web to the supports in the latter case. In order to secure sufficient bearing area at the supports and at points of heavy load concentrations, it is recommended that the routing of the flanges should be omitted at these points, and that portal stiffeners should be used. These stiffeners may be made in two sections as shown. All stiffeners with unsymmetrical sections and loaded eccentrically should be designed by the method of secondary deflections. The application and use of this method is completely covered in McCook Field report, appendix to Serial No. 1489, entitled "Experimental reinforced ply-wood truss ribs."

In the appendix there are several charts which will aid materially in the design of solid web ply-wood spars.

References: Project report L-225-1, Forest Products Laboratory, entitled "Strength tests on ply wood," and "Shear strength of ply-wood webs."


4 3/4"
1" R
4" R
1" R
4 1/2"
S @ 10" = 180"

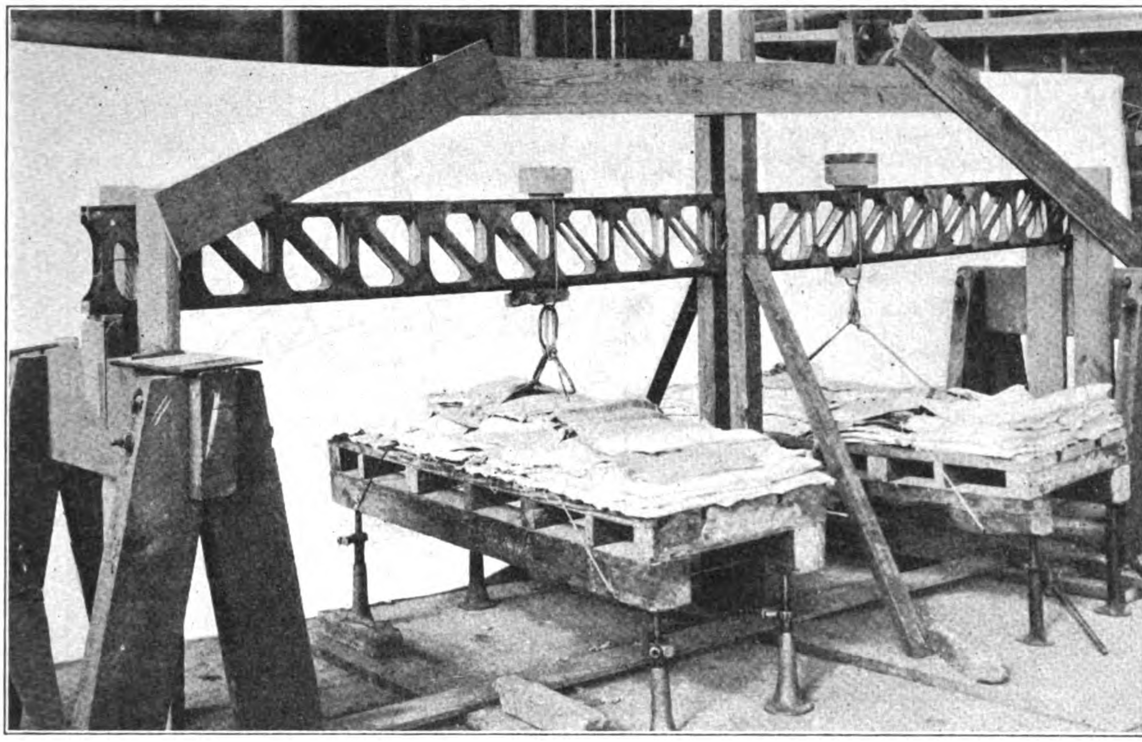


Fig. 3.

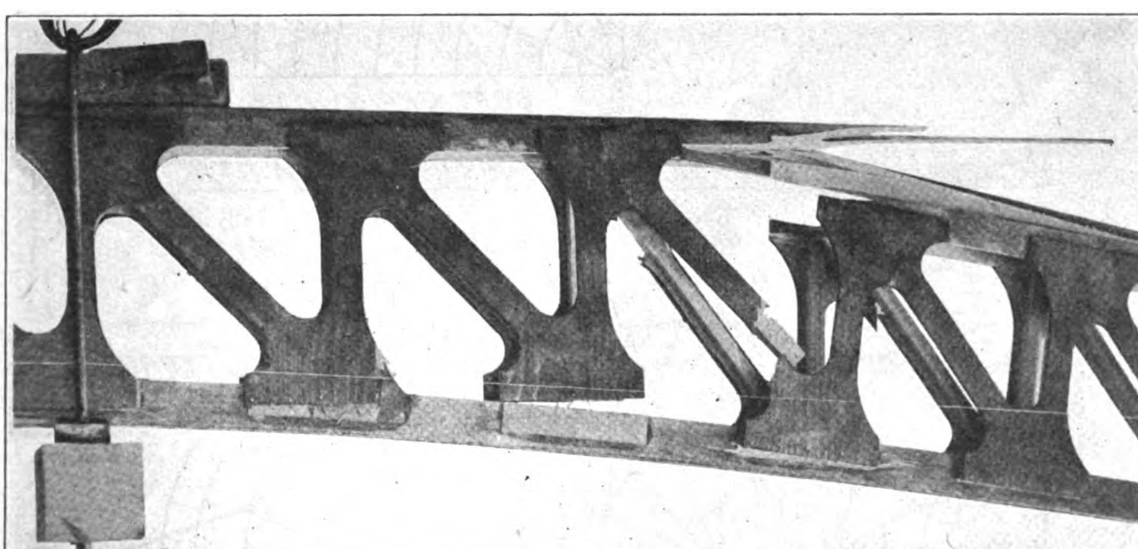


Fig. 4.

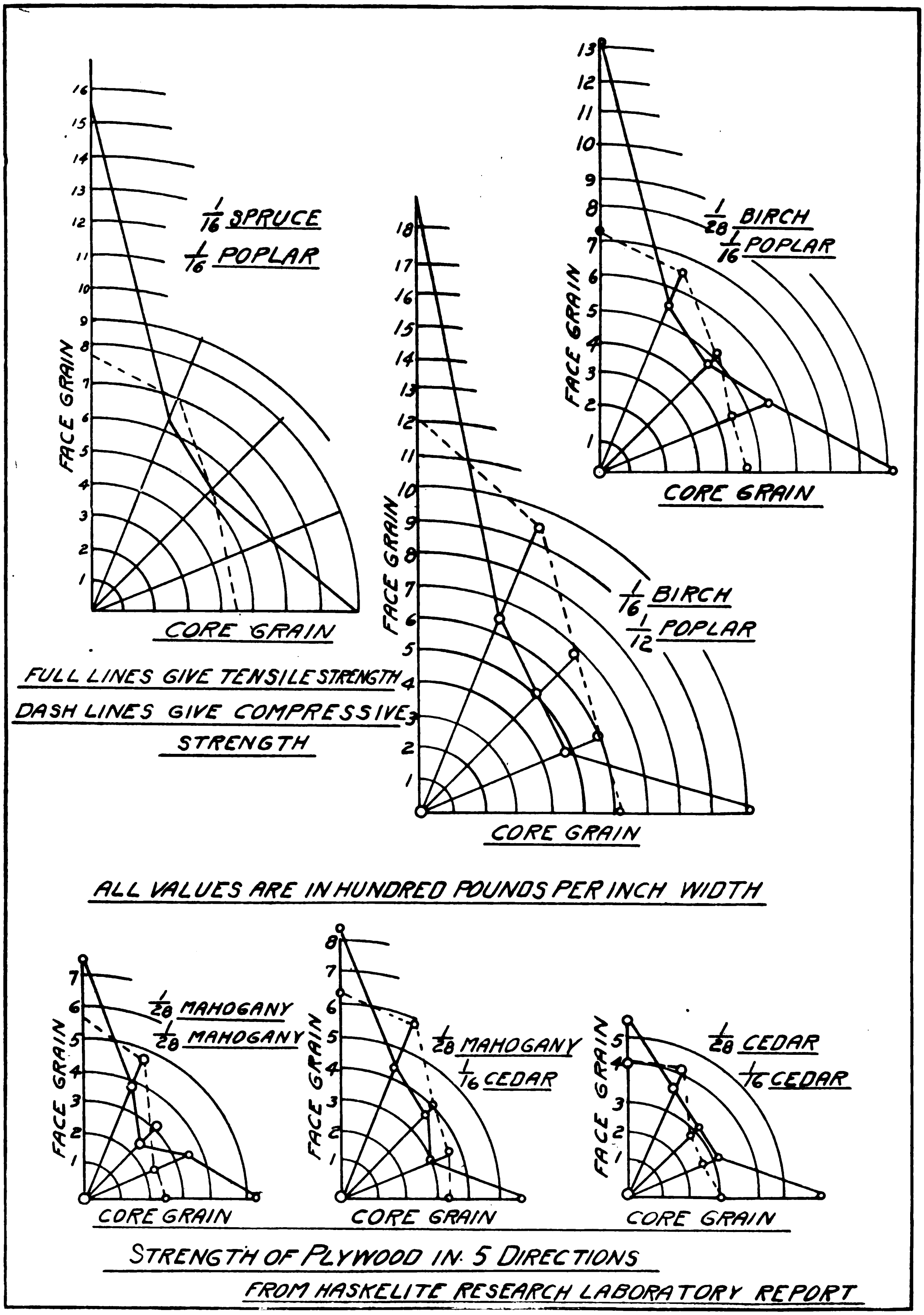
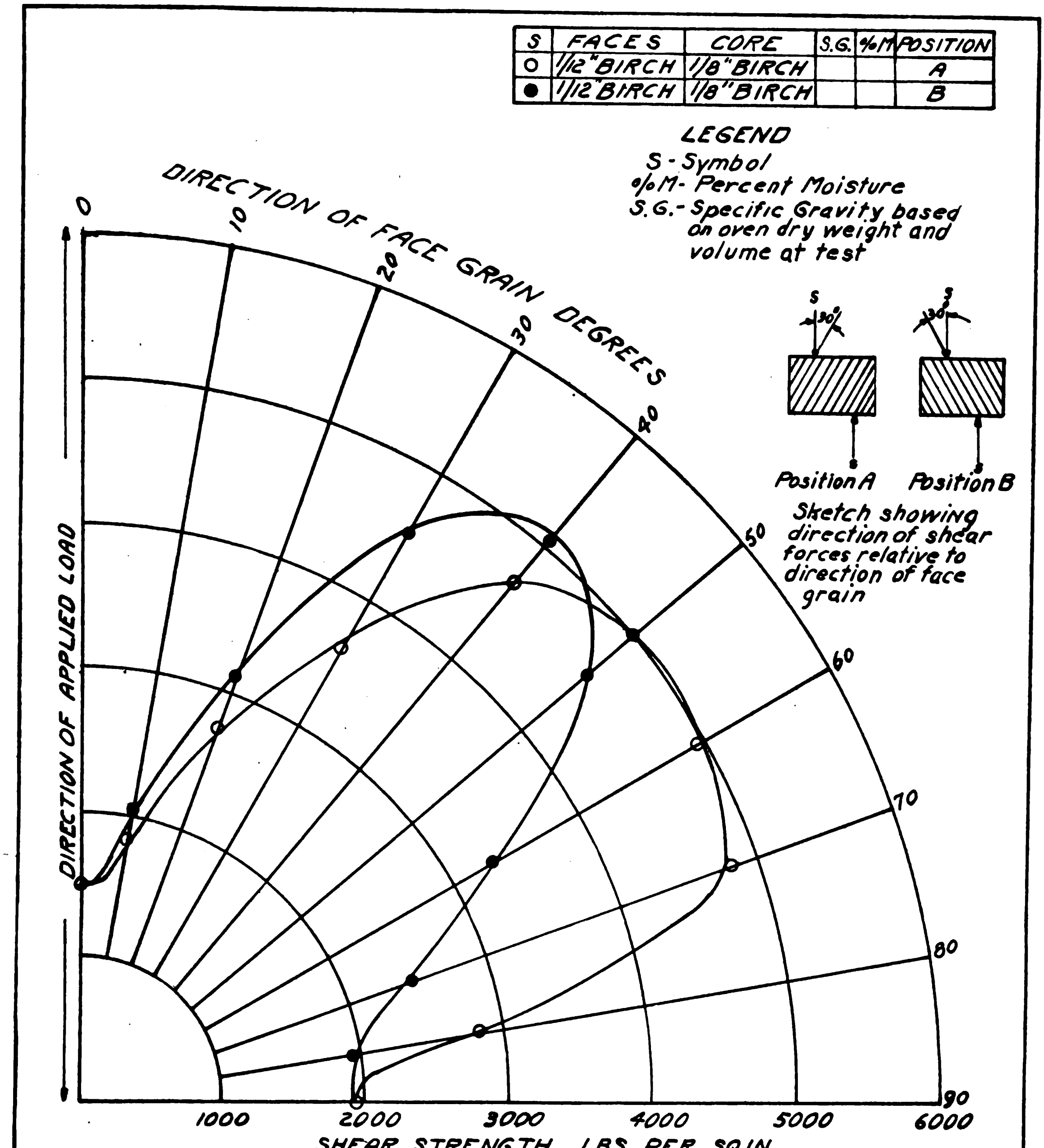

1/16 SPRUCE
1/16 POPLAR
FACE GRAIN
CORE GRAIN
FULL LINES GIVE TENSILE STRENGTH
DASH LINES GIVE COMPRESSIVE STRENGTH
1/16 BIRCH
1/12 POPLAR
FACE GRAIN
CORE GRAIN
1/28 BIRCH
1/16 POPLAR
FACE GRAIN
CORE GRAIN
ALL VALUES ARE IN HUNDRED POUNDS PER INCH WIDTH
1/28 MAHOGANY
1/28 MAHOGANY
FACE GRAIN
CORE GRAIN
1/28 MAHOGANY
1/16 CEDAR
FACE GRAIN
CORE GRAIN
1/28 CEDAR
1/16 CEDAR
FACE GRAIN
CORE GRAIN
STRENGTH OF PLYWOOD IN 5 DIRECTIONS
FROM HASKELITE RESEARCH LABORATORY REPORT

FIG. 5.



RELATION BETWEEN
UNIT SHEAR STRENGTH OF 3 PLYWOOD
AND
DIRECTION OF GRAIN

LENGTH OF SHEAR SPECIMENS 3 INCHES
DISTANCE BETWEEN SHEAR FORCES $\frac{1}{4}$ INCH

REPRODUCED FROM FOREST PRODUCTS LABORATORY REPORT

FIG. 6.

FOR OFFICIAL USE ONLY

File D 52.41.1 / Stromberg / 5 *McCOOK FIELD REPORT, SERIAL No. 1739*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV March 15, 1922 No. 314

INSTRUCTIONS FOR STROMBERG NA-L5 DOUBLE VENTURI INVERTED TYPE AIRPLANE CARBURETOR

(POWER PLANT SECTION)

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio

July 28, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INSTRUCTIONS FOR STROMBERG NA-L5 DOUBLE VENTURI INVERTED TYPE AIRPLANE CARBURETOR.

This carburetor has been especially designed for the Liberty 12 engine with supercharger installation. The float mechanism and general principals of operation are similar to those of previous Stromberg models as described in the Stromberg Airplane Carburetor Manual, but the inverted construction has necessitated changes in the detail of design.

STARTING.

Engines equipped with the inverted carburetor require much more liberal priming than engines equipped with the Zenith carburetor. These carburetors will start most readily with about eight full shots form the Lunkenheimer primer. After priming, with the throttle full closed, turn propeller over at least three cylinders. The throttle lever should then be set about 1 inch from the full closed position and the engine cranked. If these instructions are followed, the inverted carburetors give no more trouble in starting than the standard Zenith carburetors.

OPERATION.

The economical operation of this carburetor depends upon an intelligent use of the mixture control, commonly known as the altitude control. At an altitude of 5,000 feet and a cruising engine speed of 1,500 revolutions per minute the saving effected by the proper use of this control will amount to an increase of 15 per cent in the radius of action. The mixture control is of the suction bleed type with the two carburetors of one motor balanced with each other, and is effective to any altitude obtainable.

To set the control proceed as follows:

Slowly move the control lever in the "Lean" direction until the engine speed drops or the engine action becomes irregular. A slow movement of the lever is absolutely necessary on account of the appreciable length of time taken by the float chamber pressures to balance after a change of conditions. The changing conditions may cause temporary slight variations of engine speed and these should not be confused with a permanent loss of speed. When the position of lowered speed of the engine is reached, immediately bring the lever back in a "Rich" direction 2 or 3 inches and when the engine has resumed normal speed and regular action, again move the control lever in the "Lean" direction, this time to a point just short of the point of irregular action. (For more detailed information on the use of the mixture control see Air Service Information Circular, No. 257, Vol. III.)

This will be the proper control position for minimum fuel consumption at the altitude and throttle position at which the setting is made.

ADJUSTMENTS.

The metering orifices (see fig. 1) are located on either side of the float chamber at "A." A No. 42 orifice is the correct size for the Liberty 12 engine. In case of removal of these metering orifices care should be taken that the edges of the restriction in the center of the orifices are not marred and that the metering orifices do not drop into the float chamber. A brass wire or tapered stick of wood will be found useful to guide the nozzle while it is being withdrawn and to prevent it from falling into the float chamber. The mixture control should be used to regulate the mixture for varying temperature conditions. In cold weather the mixture control lever should be kept in the full rich position at ground level. In warm weather it may be set to give a leaner ground adjustment.

The idling mixture adjustments are located at "B" (see fig. 1). These operate on an air bleed and screwing them right hand inward gives less air and a richer mixture while the left-hand turn gives a leaner mixture. The idle adjusting needle should always be somewhat off the seat when the gasoline is first turned on, as otherwise the fuel may syphon over the top of the idling tube and escape into the intake manifold. Another adjustment of the utmost importance for smooth running at low speed is the throttle stop adjustment "X" (see fig. 1). It is very important that the minimum throttle openings be accurately synchronized or made equal on the front and rear carburetors, so that all cylinders are kept warm and firing properly while idling. To avoid the effect of possible lost motion in the throttle rod connections, the stop screws "X" should be adjusted in the minimum throttle opening position on both front and rear carburetors. Proper synchronization of the throttle stops will make it possible to use a considerably leaner idling mixture adjustment, as referred to in the preceding paragraph, and considerably reduce the "loading up" in gliding to a landing.

MIXTURE CONTROL COMMONLY KNOWN AS ALTITUDE CONTROL.

The mixture control valve is a separate unit and only one valve is used for two carburetors. The suction connection is made of fixed size and is taken from the small tubes "E" extending down to the throat of the small venturi. The outside air connection is regulated by the mixture control valve, the air being taken from the air scoop on top of the carburetor, or the supercharger air duct, when the latter is fitted. The air entering through the mixture control valve serves to break the partial vacuum on the float chamber caused by the suction bleed and a regulation of this air gives a consequent regulation of the pressure on the float chamber. The tubing connections should be one-half inch O. D. copper tubing with rubber hose connections. On a loop or sideslip to the left, this tubing may fill with gasoline, but it will promptly clear itself as the ship is righted. See figure 2 for proper installation and position of this valve.

FLOAT LEVEL AND DRAINS.

The float level should be 1⅜ inches to 1½ inches below the top finished faces of the carburetor main body. The carburetor has been designed so that any overflow from flooding will escape over the edge of the accelerating well

cups "C" and out through the drain connection "D." When superchargers are used, the lines from the drain connections must be fitted with shut-off valves which must be closed while the engine is running, but opened after every flight to drain out any gasoline which has collected in the carburetor. The fuel pressure should not exceed 5 pounds per square inch. To guard absolutely against the possibility of flooding the manifolds, a regular practice should be followed of shutting down the engine by shutting off the fuel, also of turning the fuel on only just before starting the engine. When the airplane is left standing out of doors for any considerable time a cover should be left over the air scoops.

STRAINER.

The strainer is located under plug "Y." The chamber may be drained of most of the accumulated dirt by removal of the drain plugs "Z." Care should be taken that this strainer space is drained and cleaned at regular intervals.

ASSEMBLY.

If for any reason the carburetors have been removed from the engine and disassembled, the following items are of primary importance in the reassembly and installation:

(1) All joints must have good gaskets and be absolutely tight. Joints to be especially watched are: Between parting surfaces of carburetor (paper), between carburetor wells and carburetor body (fiber), and between carburetor and intake header (paper). The condition of the packing and rings around the large venturi should also be checked.

(2) Before installing the carburetors on the engine the butterfly throttles of the individual carburetors should be checked; that is, the gear sectors should have no backlash, they should be securely fastened on the throttle shafts as also should the butterflys themselves, and the two butterflys should close exactly together. This latter is of the greatest importance for smooth running below 800 revolutions per minute.

(3) The throttles of the different carburetors should be synchronized as explained under "Adjustments."

(4) Great care should be taken that the mixture control connections are securely made and that the air lines are not clogged with bits of rubber or foreign matter.

For further information in regard to these carburetors address The Engineering Division, Air Service, Dayton, Ohio.

INSTRUCTIONS FOR CHANGING TO NEW TYPE IDLING ADJUSTMENTS STROMBERG INVERTED DOUBLE VENTURI MODEL NA-L5 CARBURETORS.

The following instructions are applicable to Stromberg inverted NA-L5 carburetors with the following serial numbers only:

SERIAL NUMBER.

1344788	1419776	1419789	1419804
1344790	1419777	1419790	1419805
1419765	1419778	1419791	1419806
1419766	1419779	1419794	1419807
1419767	1419780	1419795	1419808
1419768	1419781	1419796	1419809
1419769	1419782	1419797	1419810
1419770	1419783	1419798	1419811
1419771	1419784	1419799	1419812
1419772	1419785	1419800	1419813
1419773	1419786	1419801	1419814
1419774	1419787	1419802	1419815
1419775	1419788	1419803	1419816

All other carburetors were shipped from the factory with the later type of idling adjustment installed. If for any reason the serial number has been lost or become obliterated, a comparison of the carburetor with the accompanying sketches will show what type of adjustment it has.

The essential difference between the two types is that in the old type the air was drawn from the atmosphere while in the new type the air is drawn from inside of the carburetor body (see fig. 3).

After securing the new type adjustment proceed as follows:

Remove the cover from the carburetor by taking out four fillister head screws, three bolts, and idle adjustment sleeves "B." (This last will require a hexagonal socket wrench five-eighths inch across, flat). Taking care not to mar finished faces, counterbore the carburetor cover from the bottom side, nine-sixteenths of an inch diameter to a depth of one-eighth inch in the two holes for the idle adjustments. Then with a small chisel (holding the carburetor cover in the lap or on a wood bench so as not to warp it) chisel out an opening one-eighth of an inch square or larger from these counterbores to the respective air spaces of the carburetor. Then replace cover, taking care to locate gaskets properly and put in new idle adjustments with about one-thirty-second of an inch fiber washer underneath.

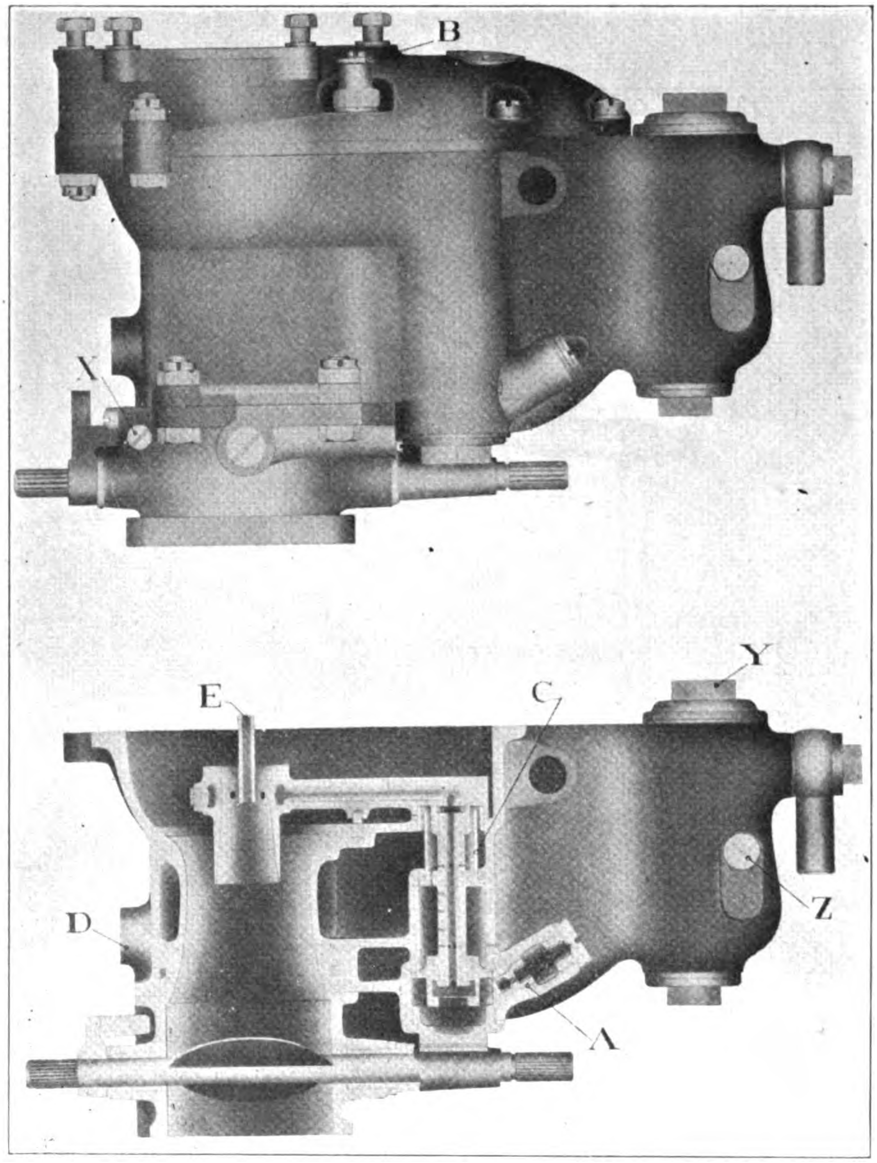


Fig. 1.—Stromberg NA-L5 double venturi inverted type carburetor.

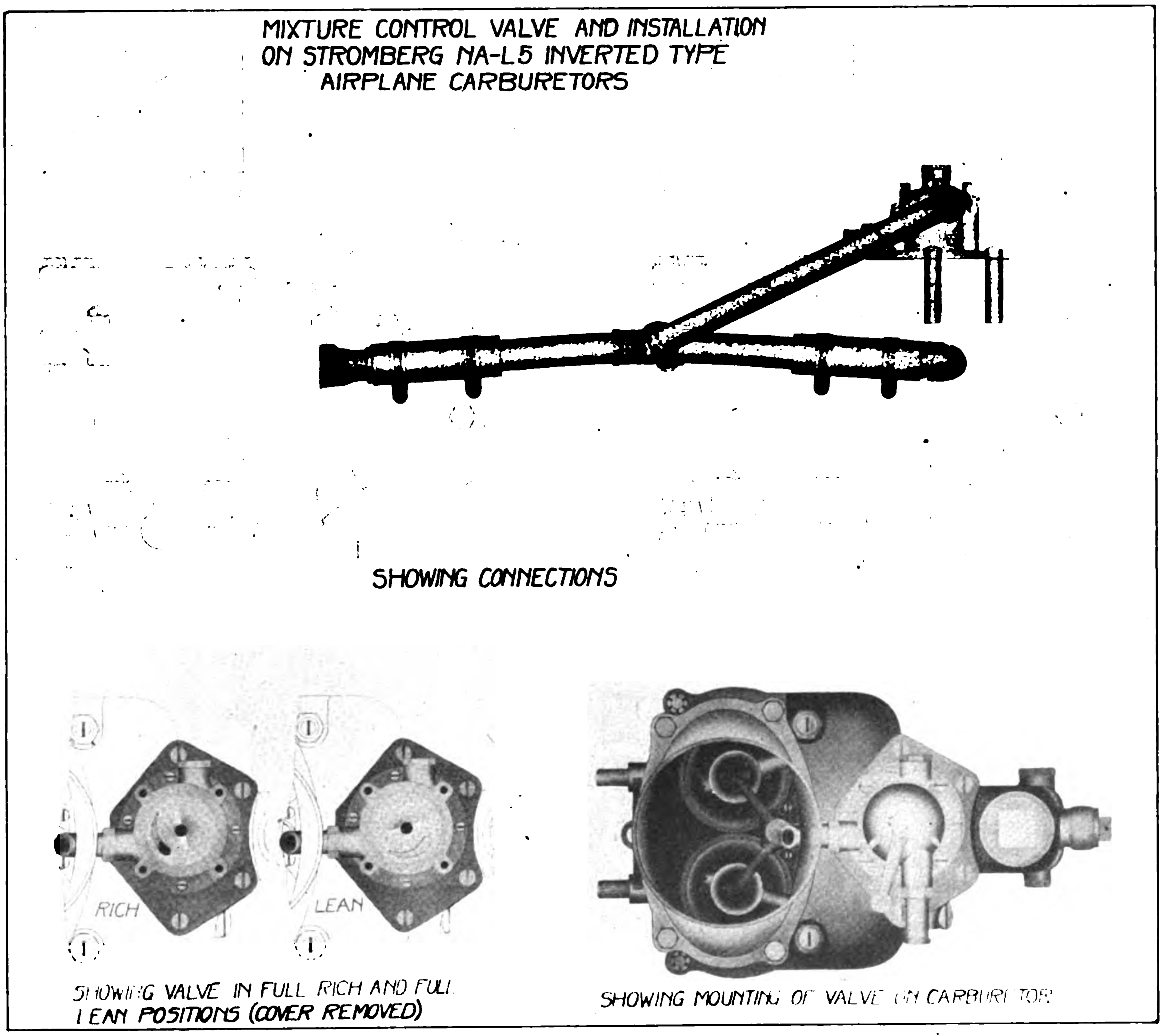

MIXTURE CONTROL VALVE AND INSTALLATION
ON STROMBERG NA-L5 INVERTED TYPE
AIRPLANE CARBURETORS
SHOWING CONNECTIONS
RICH
LEAN
SHOWING VALVE IN FULL RICH AND FULL
LEAN POSITIONS (COVER REMOVED)
SHOWING MOUNTING OF VALVE ON CARBURETOR

FIG. 2.

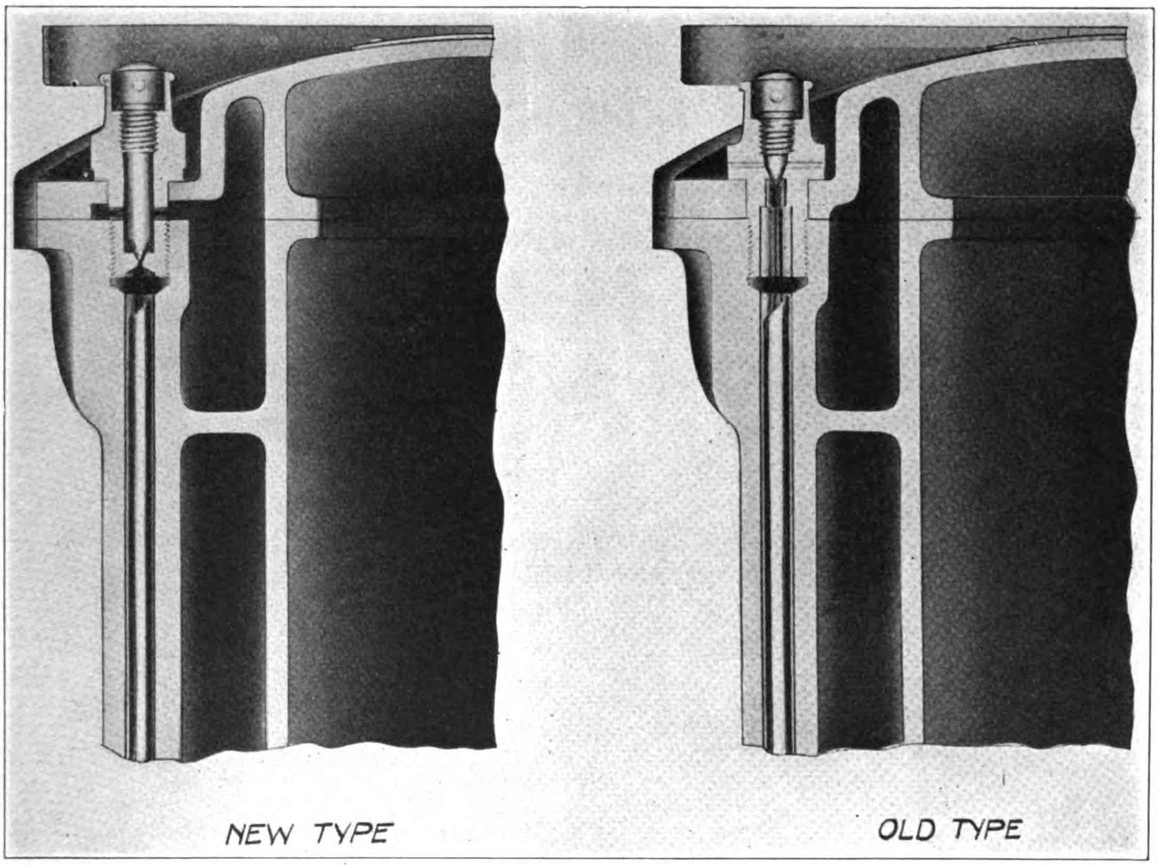


FIG. 3.—New and old type idling adjustment for Stromberg NA-L5 inverted type airplane carburetors.

McCOOK FIELD REPORT, SERIAL No. 1740

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 315

DETERMINATION OF THE BEST WING LOADING FOR SINGLE-SEATER PURSUIT AIRPLANES

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 18, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

DETERMINATION OF THE BEST WING LOADING FOR SINGLE-SEATER PURSUIT AIRPLANES.

OBJECT.

The object of the investigation covered by this report was to determine the effect of changes in wing loading and aspect ratio on the performance and weight of single-seater pursuit airplanes. This information was obtained by making six preliminary wing designs for an airplane of this type using two aspect ratios and three wing loadings. It was intended to use three aspect ratios, but that was found unnecessary. Only rough preliminary designs were made, as it was believed that the results were as good for comparative purposes as if more refined designs had been used. The type of structure and the approximations used are given below.

CONCLUSIONS.

The lighter the wing loading the better will be the performance of a single-seater pursuit airplane in most particulars. The greatest advantages are in ceiling and rate of climb, while there is a slight advantage in high speed when near the ceiling. In the cases considered, the time of climb to 15,000 feet was 35 per cent longer for the most highly loaded airplane than for the most lightly loaded one; and there was a difference of 2,600 feet between the service ceilings of the same two airplanes.

Higher speed near the ground is obtained by using a heavy loading, but this advantage disappears at altitude. At the ground the maximum difference in speed is 7.5 miles per hour. At 15,000 feet it is only 3.5 miles per hour, and above 20,000 feet the lightly loaded airplane has the higher speed. Thus, at the altitudes at which the pursuit airplane is expected to work, the lightly loaded airplane can climb higher and more quickly and can go as fast as the heavily loaded airplane.

The only effect of a change in aspect ratio on the performance is through the change in efficiency of the wings. As this effect is small in the range investigated, no allowance was made for it. The lower the aspect ratio, however, the lower will be the weight of the wing structure, as the spars will be both lighter per foot of length and shorter.

The change in performance due to a variation of 12 per cent in the weight of the wing structure is negligible.

The dead weight per square foot of the wings increases with an increase of either aspect ratio or wing loading. The maximum difference between the designs made for this report was only about 12 per cent of the total weight of the wings.

The lightest practicable wing loading should be used for single-seater pursuit airplanes. Just what this loading should be in any particular case depends on considerations of vision, maneuverability, storage, etc., which can not be compared quantitatively with performance. Therefore the exact value used must be chosen by the judgment of the designer.

METHOD OF DESIGN.

In order to reduce the labor of computation the simplest type of construction was assumed and certain assumptions were made to simplify the work still further. As a result the spar and strut sizes selected would not be the correct sizes to use in an actual design, but as the same assumptions and approximations were used for all the designs valid comparisons may be made from the data obtained. The designs were carried out following the methods outlined in "Stress Analysis and Design of Airplanes," except that drag forces were neglected and the design loads on the front and rear trusses were assumed to be 6 W and 4 W, respectively, where W was the weight of the airplane minus wings. These values are slightly higher than would be obtained from the assumed spar locations and load factors and the center of pressure travel of the aerofoil used, but were used to simplify computations.

The following data were assumed in all designs:

Aerofoil section....................R. A. F..	15
Location of the front spar in per cent of chord.....	13
Location of the rear spar in per cent of chord.......	65
Stagger....................................	None.
Efficiency of lower wing...............per cent..	90
Gap-chord ratio.............................	1.0

Spars hinged at center section.
Wing tips square.
Both wings of same span and chord.
Front and rear struts alike.
Upper and lower spars alike.

After designing the spars and struts, their weight per square foot of wing area was computed. The remainder of the wing structure, including fabric, drag trussing, etc., was assumed to have the same weight per square foot of wing area for all designs. Assuming the lightest wing to weigh 1 pound per square foot, the weights of the other wings were easily computed.

The wing loading was then revised and the power loading computed, using 328 horsepower for each design. This is the normal horsepower of the Packard-1237 engine, which is a typical engine for the type of airplane considered. For computing the fineness, an equivalent flat plate area of 5 square feet was assumed to represent the structural resistance and the fineness obtained from the chart, figure 1.

DESCRIPTION OF CHART.

In a report entitled "Airplane Performance and Design Chart"[1] it was pointed out that "fineness" depended on the parasite resistance and on the loading per square foot of wing surface. Recent developments have shown that "fineness" can be expressed as a function of equivalent flat plate area and of wing area and section. Figure 1 gives this function graphically for R. A. F. 15 wing section. It was obtained in the following manner:

Given

$$W=\delta K_y F V^2 \qquad (1)$$

and

$$\eta H.P.=(\delta K_x F V^3+0.64\,\delta A_e V^3)/550 \qquad (2)$$

where F=wing area in square feet.

η=propeller efficiency.

A_e=equivalent flat plate area of parasite resistance.

δ=density=0.00237.

V=velocity in ft./sec.

K_x and K_y in absolute units.

By the method of least squares, K_x can be expressed as a function of K_y

$$K_x=A+B\,K_y^2 \qquad (3)$$

where A=0.007 and B=0.146 for R. A. F. 15.

Simultaneous solution of equations (1), (2), and (3) yields the following:

$$550\,\eta\,H.P.=\frac{\delta A W}{\phi}V^3+\frac{B\phi W}{\delta V}+0.64\delta A_e\,V^3 \qquad (4)$$

where $\phi=\frac{W}{F}$=wing loading.

Substituting various values of $H.P.$, W, ϕ and A_e, this equation was solved for V and "fineness" then found from the "Airplane Performance and Design Chart." Figure 1 is thus obtained, and it will be noted that the relation can be expressed by one curve, "fineness"$=f(A_e/F)$. Thus it is seen that the smaller the parasite area for a given wing area, the greater the "fineness" and hence performance. An extended discussion of this subject will appear later in a special report on "fineness."

COMPUTATION OF PERFORMANCE DATA.

Knowing the wing loading, power loading, and fineness, the performances were obtained from the Airplane Performance Chart in Air Service Information Circular, Vol. II, No. 183.

Table I gives the essential data on the six designs on which this report is based, in regards to both structural weight and performance.

TABLE I.—*Weight and performance data on assumed designs.*

ϕ	Case I.	Case II.	Case III.	Case IV.	Case V.	Case VI.
Aspect ratio	5.5	5.5	5.5	5.0	5.0	5.0
Wing loading (approx.), lbs. per sq. ft	7.12	8.46	9.98	7.04	8.62	9.98
Chord, inches	70	63.5	58	74	66	61
Wing area, sq. ft	361	295	245	365	289	245.5
Spar area (one wing), sq. in	10.03	9.96	9.97	8.68	8.76	8.57
Spar weight, lbs. per ft	1.881	1.868	1.869	1.628	1.643	1.607
Spar weight, lbs. per sq. ft. of wing	0.322	0.352	0.386	0.264	0.299	0.316
Area of 1 strut, sq. in	5.53	5.04	4.56	5.72	5.09	4.71
Length of strut, inches	66	60	55	70	62	57.5
Weight of 4 struts, lbs	22.8	18.9	15.68	25.0	19.7	16.95
Weight of struts, lbs. per sq. ft. of wing	0.061	0.064	0.064	0.068	0.068	0.069
Weight of ribs, etc., lbs. per sq. ft	0.668	0.668	0.668	0.668	0.668	0.668
Weight of wings, lbs. per sq. ft	1.051	1.084	1.118	1.000	1.035	1.053
Weight of wings, lbs	379	320	274	365	299	259
Total weight, lbs	2,579	2,520	2,474	2,565	2,499	2,459
Wing loading, lbs. per sq. ft	7.14	8.54	10.10	7.03	8.65	10.01
Power loading, lbs. per h. p	7.86	7.68	7.54	7.82	7.62	7.50
Fineness	122.8	117.5	112.5	122.8	117.0	112.5
y[1]	1.66	1.89	2.11	1.66	1.90	2.10
Velocity at ground, m. p. h	146.3	149.0	153.0	145.5	149.5	153.0
Velocity at 10,000 ft., m. p. h	145.0	146.6	148.5	144.5	146.9	148.4
Velocity at 15,000 ft., m. p. h	138.6	139.7	141.3	138.1	140.1	141.0
Velocity at service ceiling, m. p. h	109.3	113.5	119.0	108.9	114.0	118.8
Climb at ground, ft. per min	1,785	1,595	1,465	1,770	1,585	1,480
Time to 10,000 ft., min	6.6—	7.5	8.5—	6.6	7.5	8.4
Time to 15,000 ft., min	12.2	14.1	16.5	12.3	14.1	16.2
Time to service ceiling, min	41.0	41.3	41.0	41.5	41.2	41.0
Service ceiling, ft	24,025	22,900	21,400	24,050	22,800	21,000
Velocity at 20,000 ft. (interpolated from curves), m. p. h	126.8	126.7	126.6	126.5	127.3	126.6—

[1] y is the ordinate on the performance chart for the given power loading and fineness.

Several interesting facts were brought out in the computations for the six designs in addition to the main conclusions given above.

1. For a given aspect ratio and gap-chord ratio and varying wing loadings, the net area of spars tends to be constant. The areas of the spars of the designs in question were not exactly constant, but the differences were apparently due mainly if not entirely to the variations in the efficiency with which the material was used. With the higher wing loadings the moments are smaller, but this is counteracted by the decrease in the depth of the spars, so the same sectional area must be used.

2. The direct stresses in the lift trusses do not vary with either aspect ratio or wing loading, but only with the proportions of the truss. A change in the gap-chord ratio or the ratio of cantilever length to length of bay will cause a change in the direct stresses.

3. With a given gap-chord ratio the size of the struts varies with the chord, but for a given aspect ratio the weight of struts per square foot of wing is constant.

4. In figure 1 the fineness is independent of the aspect ratio. Therefore, the effect on performance of a change of aspect ratio is only the negligible changes due to the variation in the structural weight and efficiency of the wings.

[1] Air Service Information Circular, Vol. II, No. 183. McCook Field Report No. 1380.

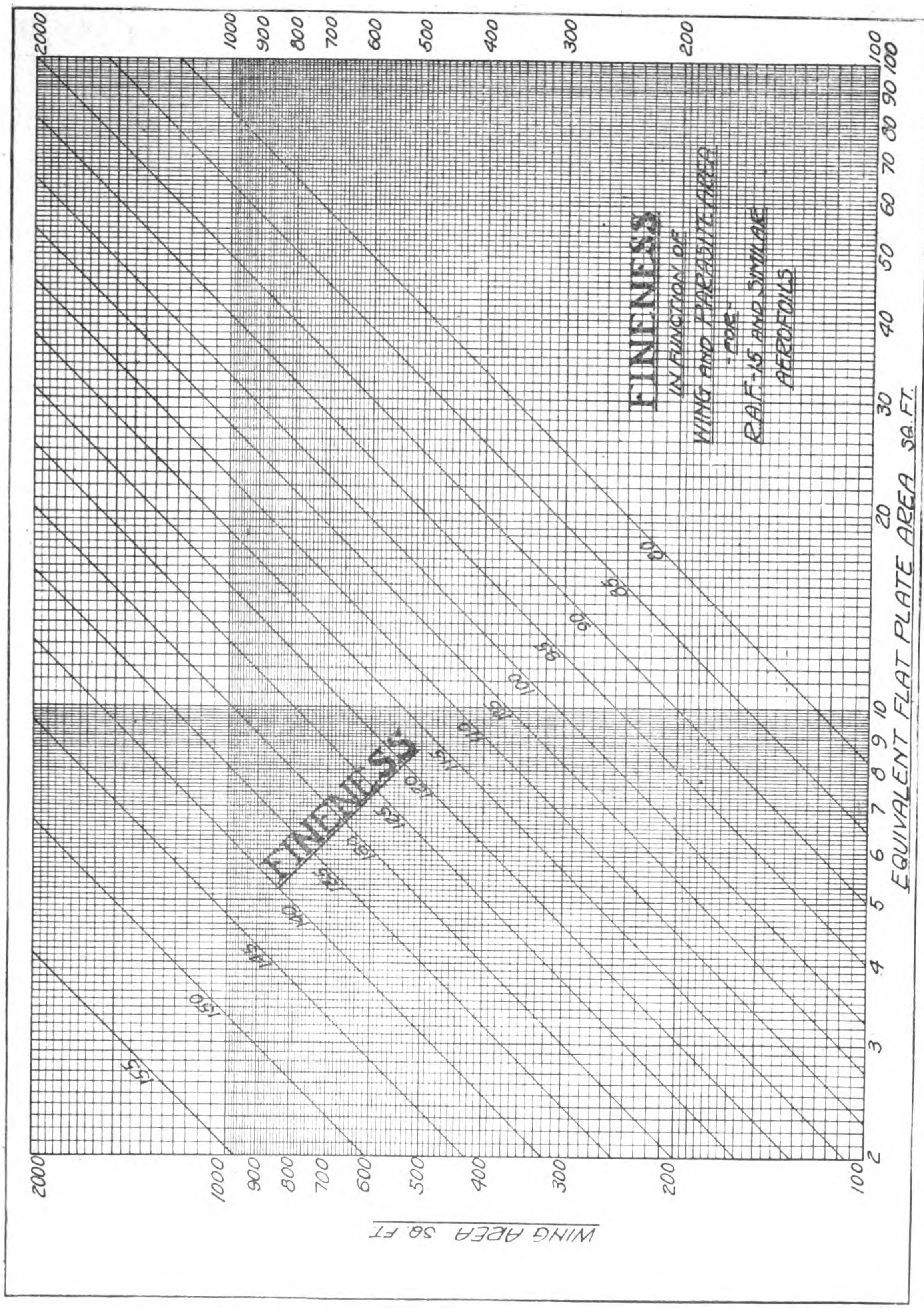

FINENESS
IN FUNCTION OF
WING AND PARASITIC AREA
-FOR-
R.A.F.-15 AND SIMILAR
AEROFOILS
EQUIVALENT FLAT PLATE AREA SQ. FT.
WING AREA SQ. FT.
FINENESS

FIG. 1.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV March 15, 1922 No. 317

METHOD FOR ESTIMATING POWER AND FUEL CONSUMPTION OF NORMAL COMPRESSION AVIATION ENGINES IN FLIGHT AT VARIOUS ALTITUDES

(POWER PLANT SECTION REPORT)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
September 1, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

4 … 317

File D 52.45/82. (C. A. S. I. C. 4.)

AIR SERVICE INFORMATION CIRCULAR.

(AVIATION.)

CHANGES No. 4.

WAR DEPARTMENT, AIR SERVICE,
August 15, 1922.

Page 5, Table II, sections A and B, and page 6, Table IIa, inclusive, Air Service Information Circular, Volume IV, No. 317, and Changes No. 3, Air Service Information Circular, Volume IV, No. 317, "Method for Estimating Power and Fuel Consumption of Normal Compression Aviation Engines in Flight at Various Altitudes," are changed, by direction of the Chief of Air Service, in accordance with recommendation of the Engineering Division contained in a letter dated July 7, 1922, as follows:

Page 5, Table II, sections A and B, substitute the following:

TABLE II.—*Estimated full-throttle horsepower at actual revolutions per minute at sea level and various altitudes.*[1]

SECTION A.—NORMAL COMPRESSION RATIOS APPROXIMATELY 5-5.5:1.

Engine and class of service.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower at actual revolutions per minute.[2] Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Training:									
Aeromarine	U-8-D	1,600	560	180	148	117	90	64	39
Curtiss	OX-5	1,400	385	90	74	59	45	32	20
Curtiss	C-6	1,750	450	160	132	104	80	57	35
Lawrance	J-1	1,650	447	180	148	117	90	64	39
Le Rhone	C	1,200	260	[3] 80	66	52	40	29	17
Le Rhone	Jb	1,200	320	[3] 120	99	78	60	43	26
Liberty [4]	"6"	1,700	635	200	165	130	100	72	44
Packard	825	1,450	555	180	148	117	90	64	39
Rausie	E-6	1,650	550	160	132	104	80	57	35
Wright-Hispano	E-2	1,700	475	180	148	117	90	64	39
Wright-Hispano	I	1,700	470	180	148	117	90	64	39
Alert:									
Aeromarine	U-8-D	2,000	560	200	165	130	100	72	44
Lawrance	J-1	1,800	447	[5] 200	165	130	100	72	44
Le Rhone	R	1,350	380	160	132	104	80	57	35
Packard	825	2,000	555	225	186	147	113	81	49
Wright-Hispano	E-2	2,000	475	210	173	137	105	75	46
Pursuit:									
Almen	Barrel	2,000	725	[6] 375	309	245	188	134	82
Curtiss	CD-12	2,000	705	375	309	245	188	134	82
Packard	1237	1,800	740	[6] 325	268	212	163	116	71
Wright-Hispano	H	1,800	635	310	256	202	156	111	68
Wright-Hispano	H-3	1,800	620	315	260	205	158	113	69
Wright-Hispano	H-3	2,000	620	350	289	228	176	125	76
Wright	Radial	1,650	[5] 885	[5] 350	289	228	176	125	76
Observation and bombardment:									
Liberty	"12"	1,700	[7] 845	400	330	261	201	143	87
Liberty [8]	"12"	1,700	1,010	400	400	400	400	400	333
McCook	W-1	1,700	1,815	700	578	456	351	250	153
McCook	W-2	1,400	[5] 2,400	[5] 1,000	825	652	502	358	218
Packard	2025	1,700	1,170	520	429	339	261	186	113
Miscellaneous:									
Lawrance	"L" series	1,700	160	55	45	36	28	20	12
Lawrance	Torpedo	1,800	155	60	49	39	30	21	13

[1] Add 10 per cent to power output in making computations for cooling systems. The performance estimates are based on actual tests except in instances where reference is made to footnotes 3 and 5. In most cases the estimates are lower than the test results to allow for variation between engines, atmospheric variations, etc.

[2] Allowing for drop in engine propeller speed based on average drop observed on numerous tests of Liberty and Wright-Hispano engines.

[3] Rated power. Actual developed power not known.

[4] Equipped with magneto ignition.

[5] Estimated. (Engines under construction; in most cases no test data or weights are available.)

[6] Power output obtained from report by Packard Motor Car Co. No engines of this type (with low compression) are planned for production.

[7] Weight is with Zenith U. S. 52 carburetors. With inverted carburetors weight is 860 pounds.

[8] Equipped with General Electric supercharger. Power output assumed constant to 20,000 feet and then to decrease with decrease in density.

(C. A. S. I. C. 4.)

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

4655—22

Table II.—*Estimated full-throttle horsepower at actual revolutions per minute at sea level and various altitudes*—Contd.

SECTION B.—HIGH-COMPRESSION RATIO OF 6½ : 1.

Engine and class of service.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower, unblended gasoline. Sea level.	Horsepower, unblended gasoline. 5,000 feet.[10]	Horsepower with doped fuel.[9] Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Training:											
Aeromarine	U-8-D	1,600	560	147	147	195	161	127	98	70	43
Curtiss	C-6	1,750	450	132	132	175	144	114	88	63	38
Lawrance	J-1	1,650	447	147	147	195	161	127	98	70	43
Liberty	"6"	1,700	635	162	162	215	177	140	108	77	47
Packard	825	1,450	555	147	147	195	161	127	98	70	43
Wright-Hispano	E-2	1,700	475	147	147	195	161	127	98	70	43
Alert:											
Aeromarine	U-8-D	2,000	560	162	162	215	177	140	108	77	47
Lawrance	J-1	1,800	447	162	162	215	177	140	108	77	47
Packard	825	2,000	555	180	180	240	198	157	121	86	52
Wright-Hispano	E-2	2,000	475	169	169	225	186	147	113	81	49
Pursuit:											
Almen	Barrel	2,000	725	305	305	405	334	264	203	145	88
Curtiss	CD-12	2,000	705	305	305	405	334	264	203	145	88
Packard	1237	1,800	740	263	263	350	289	228	176	125	76
Wright-Hispano[11]	H-3	1,800	620	256	256	340	280	221	171	122	74
Wright-Hispano[11]	H-3	2,000	620	282	282	375	309	245	188	134	82
Wright	Radial	1,650	[12] 885	286	286	380	313	248	191	136	83
Observation and bombardment:											
Liberty[11]	"12"	1,700	845	338	338	450	371	294	226	161	98
McCook	W-1	1,700	1,815	568	568	755	623	492	379	270	165
McCook	W-2	1,400	[12] 2,400	812	812	1,080	891	704	542	387	235
Packard	2,025	1,700	1,170	423	423	562	464	366	282	201	123

[9] Allowing for drop in engine-propeller speed based on average drop observed on numerous tests of Liberty and Wright-Hispano engines with normal compression ratios. While tests show that the drop is not quite as great for the high-compression ratio, the absolute difference is small enough to be disregarded for the sake of simplicity.

[10] This horsepower is maintained (by throttling) to 7,000 feet. Above 7,000 feet, values are the same as for operation with doped fuel.

[11] Increase of sea-level horsepower with 6½:1 compression ratio obtained from actual tests of high-compression engines compared with output with 5–5½:1 compression ratios. For the other engines the sea-level horsepower (using doped fuel) was estimated to be 8 per cent greater than the sea-level horsepower with 5–5½:1 compression ratios.

[12] Estimated.

(*C. A. S. I. C. 4.*)

Page 6, Table IIa, substitute the following:

Table IIA.—*Estimated full-throttle fuel and oil consumption in pounds per hour at sea level and various altitudes for both normal and high-compression ratios.*[1]

Engine and class of service.	Model.	Normal revolutions per minute.	Fuel consumption, unblended gasoline.[2] Sea level.	Fuel consumption, unblended gasoline.[2] 5,000 feet.	Hourly fuel consumption in pounds.[1] Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.	Oil consumed, pounds per hour.
Training:											
Aeromarine	U-8-D	1,600	76	76	97	83	68	56	50	48	7.2
Curtiss	OX-5	1,400	(3)	(3)	49	42	34	28	25	24	3.6
Curtiss	C-6	1,750	68	68	86	74	61	50	44	43	6.4
Lawrance	J-1	1,650	81	81	103	88	73	60	53	51	10.8
Le Rhone	C	1,200	(3)	(3)	64	55	45	37	33	32	6.4
Le Rhone	Jb	1,200	(3)	(3)	96	82	68	56	49	48	9.6
Liberty	"6"	1,700	85	85	108	92	76	63	56	54	8.0
Packard	825	1,450	76	76	97	83	68	56	50	48	7.2
Rausie	E-6	1,650	(3)	(3)	86	74	61	50	44	43	6.4
Wright-Hispano	E-2	1,700	76	76	97	83	68	56	50	48	7.2
Wright-Hispano	I	1,700	(3)	(3)	97	83	68	56	50	48	7.2
Alert:											
Aeromarine	U-8-D	2,000	85	85	108	92	76	63	56	54	8.0
Lawrance	J-1	1,800	90	90	114	98	80	66	59	57	12.0
Le Rhone	R	1,350	(3)	(3)	128	109	90	74	66	64	12.8
Packard	825	2,000	96	96	122	104	86	71	63	61	9.0
Wright-Hispano	E-2	2,000	89	89	113	97	80	66	58	56	8.4
Pursuit:											
Almen	Barrel	2,000	160	160	203	173	143	118	104	101	22.5
Curtiss	CD-12	2,000	160	160	203	173	143	118	104	101	15.0
Packard	1237	1,800	138	138	175	150	123	102	90	87	13.0
Wright-Hispano	H	1,800	(3)	(3)	167	143	118	97	86	83	12.4
Wright-Hispano	H-3	1,800	134	134	170	145	120	99	87	84	12.6
Wright-Hispano	H-3	2,000	149	149	189	162	133	110	97	94	14.0
Wright	Radial	1,650	158	158	200	171	141	116	103	99	21.0
Observation and bombardment:											
Liberty	"12"	1,700	170	170	216	185	152	125	111	107	16.0
Liberty (supercharged)	"12"	1,700	(4)	(4)	216	216	216	216	216	200	16.0
McCook	W-1	1,700	298	298	378	323	266	219	194	188	28.0
McCook	W-2	1,400	426	426	540	462	380	313	278	268	40.0
Packard	2025	1,700	221	221	281	240	198	163	145	140	20.8
Miscellaneous:											
Lawrance	"L" series	1,700	(3)	(3)	31	27	22	18	16	15	3.3
Lawrance	Torpedo	1,800	(3)	(3)	34	29	24	20	18	17	3.6

[1] The hourly fuel consumption for both normal and high-compression ratios is assumed to be the same at a given speed, since no changes in carburetor setting are contemplated or are generally necessary. However, with the high ratios "doped" fuel must be used.

[2] This data applies only to high-compression engines which have to be throttled at sea level and up to 7,000 feet to avoid detonation. This fuel consumption is maintained to 7,000 feet. Above 7,000 feet, values are the same as for operation with doped fuel.

[3] These engines will not be equipped with high-compression ratio.

[4] The supercharged Liberty does not have to be run throttled, as explained in footnote 3.

(*C. A. S. I. C. 4.*)

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1922

METHOD FOR ESTIMATING POWER AND FUEL CONSUMPTION OF NORMAL COMPRESSION AVIATION ENGINES IN FLIGHT AT VARIOUS ALTITUDES.

OBJECT.

The object of this report is to furnish a standard method for estimating performance of normal compression engines in flight at various altitudes.

SUMMARY OF RESULTS.

Figures for estimating the altitude performance of normal compression engines are given in Table I.

In the case of the normal engines it is necessary to know the sea-level horsepower of the engine at the normal operating speed, and the hourly fuel consumption at that speed. The table gives values for altitudes other than sea level in per cent of the sea-level quantities.

In Table II the performance data for a number of representative engines have been computed, using the figures given in Table I.

A report on the methods used in estimating the performance at altitudes of overdimensioned and overcompressed engines is in preparation and will be issued as a supplement to this report, when completed

METHOD OF COMPUTATION.

At the present time the only reliable data available on engine performance at various altitudes are those which have been obtained on a few airplane engines in the altitude chamber at the Bureau of Standards. Any estimate of altitude performance must be based on these results, since no others are available. The results obtained in the altitude chamber differ from conditions of actual flight in the following respects:

(*a*) The engine speed has been held constant with varying altitude.

(*b*) The atmospheric conditions actually existing at various altitudes have not been accurately duplicated.

(*c*) The engine is run under conditions more favorable to good performance than is the case in actual service.

In estimating service performance, therefore, allowance must be made for the above discrepancies.

The performance estimates given herewith are based on results of Bureau of Standards altitude chamber tests on three representative service engines and on a large number of flights tests with different engine-propeller-airplane combinations. The method of compiling these data and of making allowance for the difference between altitude chamber results and actual service is described hereinafter.

Table III is a summary of the power results of the altitude chamber tests of the Liberty 12, the Hispano-Suiza model "H," and the Hispano-Suiza model "E" engines. The figures given are the average of the results on these engines, each operating at two different speeds. These data do not allow for the drop in speed of the engine-propeller unit, but merely represent the average test block results where the speed was held constant and other conditions of the test were controlled carefully.

Table IV: In order to estimate the power output in flight, it is not enough merely to correct for changes due to decreasing density, but some allowance must be made for drop in speed of the engine-propeller unit. The figures given in this table represent the average drop in speed with altitude of 13 engine-propeller-airplane units in flight, consisting of eight Liberty 12, four Hispano-Suiza model "H," and one Hispano-Suiza model "E" engines.

Table V: This table gives the variation in horsepower with altitude, taking into account the drop in speed of the engine-propeller unit with increasing altitude. The data of Table V are obtained by multiplying the data of Table III by those of Table IV at each altitude. For instance, the horsepower at 15,000 feet, at constant speed, is 53.7 per cent of the sea-level horsepower (Table III). At 15,000 feet the speed of the engine-propeller unit is 93.4 per cent of its speed at sea level (Table IV). The product of 0.537 and 0.934 is 0.502, and the horsepower, therefore, of an engine mounted in an airplane at 15,000 feet is assumed to be 50.2 per cent of the sea-level data (Table V). This computation is made on the assumption that the horsepower is directly proportional to the engine speed. Such an assumption is allowable, as the actual difference in speed is small. The error is within the limits of accuracy of those performance estimates.

The power output variation as given in this table forms the basis for the estimate of hourly fuel consumption.

Table VI: The brake specific fuel consumption increases with altitude, due largely to the decrease in mechanical efficiency. This table shows the average variation in the brake specific fuel consumption with altitude obtained on tests run in the altitude chamber of the Bureau of Standards on the model "H" Hispano-Suiza and the 12-cylinder Liberty engines each operating at two speeds. The original data from which the figures for each altitude were obtained can be found in Engineering Division Reports, Serials Nos. 1232 and 1233.

Table VII: The hourly fuel consumption at various altitudes is expressed in this table as a percentage of the quantity of fuel consumed in one hour at sea level. The data are obtained by multiplying together the values tabulated in Tables V and VI at any given altitude. For instance, the horsepower at 20,000 feet, allowing for drop in speed, is 35.8 per cent of the sea-level horsepower (Table V). The specific fuel consumption at this altitude is 144.1 per cent of the sea-level consumption (Table VI). The product of 0.358 and 1.441 is 0.514, and the hourly fuel consumption at 20,000 feet is, therefore, taken to be 51.4 per cent of the hourly fuel consumption at sea level.

Referring to page 3, item (*a*) has been allowed for by correcting for the variation in speed as already explained. The difference in atmospheric conditions between the altitude chamber tests and actual flight, item (*b*), consists largely in differences in temperature at the higher altitude, the temperatures in the chamber averaging higher than actual temperatures at the corresponding altitudes. Since no reliable method for correcting for temperature is available, this difference can not be allowed for in the tables. Indications are, however, that the effect on engine performance of these temperature differences is so small as to be well within the limits of accuracy of these tables.

In regard to item (*c*), it is believed that the rate of change of power and fuel consumption with altitude is not greatly different in the altitude laboratory and in flight, provided the carburetor altitude control is properly handled in both cases. It is sufficient, therefore, to allow for the more favorable laboratory conditions in the absolute values of the power and fuel consumption at sea level. The following allowances are therefore recommended:

(*a*) *Horsepower.*—Where test results are available on a number of engines of the type in question, the average of these results should be taken as the sea-level value to be substituted in the tables. Where a laboratory test on one engine only is available, the sea-level horsepower should be reduced by 5 per cent to allow for the less favorable flight conditions and the variation between different engines of the same model.

(*b*) *Fuel consumption.*—Experience has shown that the fuel consumption obtained on test is always lower than that in flight. The following values are therefore recommended as representing average specific fuel consumption in flight at sea level:

	Pound per horse-power hour.
Water-cooled engines	0. 54
Air-cooled radials	. 57
Rotary engines	. 80

(*c*) The oil consumption of different engines, even of the same model, varies enormously. In estimating oil consumption, the maximum probable consumption should be used. Rather than depend on laboratory tests of a limited number of engines, the following values are recommended for normal engines:

	Pound per horse-power hour.
Vertical and "V" engines	0. 04
Radial engine	. 07
Rotary engines	. 08

The Air Service plans to reject or re-overhaul engines which exceed the above oil consumptions. Since data on oil consumption at various altitudes are lacking, it should be assumed that the hourly oil consumption of all engines is the same at all altitudes as at sea level.

INSTRUCTIONS FOR ESTIMATING POWER AND FUEL CONSUMPTION.

For normal engines.—Use columns A and B of Table I. Determine the horsepower at sea level. The horsepower at altitude will bear the same relation to the sea-level horsepower as the percentages in column A. Determine the hourly fuel consumption at sea level, which is the product of the sea-level horsepower and the specific brake fuel consumption at sea level. The hourly fuel consumption at other altitudes will bear the same relation to the sea-level consumption as the percentages in column B.

For instance, given that the output at sea level at the normal speed of the Liberty engine is 400 horsepower and its brake specific fuel consumption is 0.540 pound per horsepower hour and oil consumption 0.04 pound per horsepower hour, to find the power output and hourly fuel and oil consumption at 15,000 feet.

From column A, the horsepower at 15,000 feet is 50.2 per cent of the sea-level horsepower or $400 \times 0.502 = 200.8$ horsepower.

The hourly fuel consumption at sea level would be $400 \times 0.540 = 216$ pounds.

From column B, the hourly fuel consumption at 15,000 feet is 58 per cent of the sea-level consumption, or $216 \times 0.58 = 125.3$ pounds.

The oil consumption is 400×0.04, or 16 pounds per hour for all altitudes.

The same method is followed for other altitudes.

TABLE I.—*Per cent variation in performance at altitude of normal engines, allowing for change in speed of engine-propeller unit.*

Altitude.	Normal engines.	
	A Horse-power.[1]	B Hourly fuel consumption.[2]
Sea level	100.0	100.0
5,000 feet	82.5	85.5
10,000 feet	65.2	70.4
15,000 feet	50.2	58.0
20,000 feet	35.8	51.4
25,000 feet	21.8	49.7

[1] See Table V. [2] See Table VII.

TABLE II.—*Estimated full-throttle horsepower at actual revolutions per minute at sea level and various altitudes.*[1]

SECTION A.—NORMAL COMPRESSION RATIOS APPROXIMATELY 5–5½ : 1.

Engine.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower at actual revolutions per minute.[2]					
				Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Liberty [3]	6	1,700	635	200	165	130	100	72	44
Liberty	12	1,700	[4] 845	400	330	261	201	143	87
Liberty [5]	12	1,700	1,010	400	400	400	400	400	333
Packard	825	1,800	555	215	177	140	108	77	47
Packard [6]	1237	1,800	740	325	268	212	163	116	71
Packard	2025	1,800	1,170	540	446	352	271	193	118
Wright Hispano	I	1,450	470	154	127	101	77	55	34
Wright Hispano [7]	E-2	1,800	475	190	157	124	95	68	41
Wright Hispano [8]	E-2	2,000	475	210	173	137	105	75	46
Wright Hispano	H	1,800	635	310	256	202	156	111	68
Wright Hispano	H-3	2,000	620	350	289	228	176	125	76
Wright	Radial	1,800	[9] 885	[9] 350	289	228	176	125	76
Lawrance	3 cyl	1,600	150	50	41	33	25	18	11
Lawrance	R-1	1,600	400	140	116	91	70	50	31
Lawrance	J-1	1,800	[9] 435	[9] 200	165	130	100	72	44
Le Rhone	C	1,200	260	[10] 80	66	52	40	29	17
Le Rhone	J-b	1,200	320	[10] 120	99	78	60	43	26
Le Rhone	R	1,350	380	[10] 180	148	117	90	64	39
Curtiss	OX-5	1,400	385	[10] 90	74	59	45	32	20
Curtiss	C-6	1,750	450	160	132	104	80	57	35
Curtiss (direct)	C-12	2,000	705	375	309	245	188	134	82
Rausie	E-6	1,650	550	160	132	104	80	57	35
Aeromarine	U-8-D	1,600	560	170	140	111	85	61	37
Almen	Barrel	2,000	[9] 700	[9] 375	309	245	188	134	82
McCook	W-1	1,700	1,700	700	578	456	351	250	153
McCook	W-2	1,400	[9] 2,400	[9] 1,000	825	652	502	358	218

[1] Add 10 per cent to power output in making computations for cooling systems. The performance estimates are based on actual tests except in instances where reference is made to footnotes 9 and 10. In most cases, the estimates are lower than the test results to allow for variation between engines, atmospheric variations, etc.

[2] Allowing for drop in engine propeller speed based on average drop observed on numerous tests of Liberty and Wright Hispano engines.

[3] Equipped with magneto ignition.

[4] Weight is with Zenith U. S. 52 carburetors. With inverted carburetors weight is 860 pounds.

[5] Equipped with General Electric supercharger. Power output assumed constant to 20,000 feet and then to decrease with decrease in density.

[6] Power output obtained from report by Packard Motor Car Co.

[7] Training.

[8] Alert.

[9] Estimated. (Engines under construction: in most cases no test data or weights are available.)

[10] Rated power. Actual developed power not known.

SECTION B.—HIGH COMPRESSION RATIO OF 6½ : 1.

Engine.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower, unblended gasoline.		Horsepower with doped fuel.[11]					
				Sea level.	5,000 feet.[12]	Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Liberty	6	1,700	635	162	162	215	177	140	108	77	47
Liberty [13]	12	1,700	845	338	338	450	371	294	226	161	98
Packard	825	1,800	555	177	177	235	194	153	118	84	51
Packard	1237	1,800	740	263	263	350	289	228	176	125	76
Packard	2025	1,800	1,170	440	440	585	483	381	294	209	128
Wright Hispano	I	1,450	470	124	124	165	136	108	83	59	36
Wright Hispano	E-2	1,800	475	154	154	205	169	134	103	73	45
Wright Hispano	E-2	2,000	475	169	169	225	186	147	113	81	49
Wright Hispano [13]	H	1,800	635	252	252	335	276	218	168	120	73
Wright Hispano [13]	H-3	2,000	620	282	282	375	309	245	188	134	82
Wright	Radial	1,800	[14] 885	286	286	380	313	248	191	136	83
Lawrance	3 cyl	1,600	150	41	41	55	45	36	28	20	12
Lawrance	R-1	1,600	400	113	113	150	124	98	75	54	33
Lawrance	J-1	1,800	[14] 435	162	162	215	177	140	108	77	47
Le Rhone	C	1,200	260	64	64	[15] 85	70	55	43	30	19
Le Rhone	J-b	1,200	320	98	98	[15] 130	107	85	65	47	28
Le Rhone	R	1,350	380	147	147	[15] 195	161	127	98	70	43
Curtiss	OX-5	1,400	385	71	71	95	78	62	48	34	21
Curtiss	C-6	1,750	450	132	132	175	144	114	88	63	38
Curtiss (direct)	C-12	2,000	705	305	305	405	334	264	203	145	88
Rausie	E-6	1,650	550	132	132	175	144	114	88	63	38
Aeromarine	U-8-D	1,600	560	139	139	185	153	121	93	66	40
Almen	Barrel	2,000	[14] 700	305	305	405	334	264	203	145	88
McCook	W-1	1,700	1,700	568	568	755	623	492	379	270	165
McCook	W-2	1,400	[14] 2,400	812	812	1,080	891	704	542	387	235

[11] Allowing for drop in engine-propeller speed based on average drop observed on numerous tests of Liberty and Wright Hispano engines with normal compression ratios. While tests show that the drop is not quite as great for the high-compression ratio, the absolute difference is small enough to be disregarded for the sake of simplicity.

[12] This horsepower is maintained (by throttling) to 7,000 feet. Above 7,000 feet values are the same as for operation with doped fuel.

[13] Increase of sea-level horsepower with 6½ : 1 compression ratio obtained from actual tests of high-compression engines compared with output with 5–5½ : 1 compression ratios. For the other engines the sea-level horsepower (using doped fuel) was estimated to be 8 per cent greater than the sea-level horsepower with 5–5½ : 1 compression ratios.

[14] Estimated.

[15] Very questionable, since data on high-compression rotaries are lacking.

Table IIa.—*Estimated full-throttle fuel and oil consumption in pounds per hour at sea level and various altitudes for both normal and high compression ratios.*[1]

Engine.	Model.	Normal revolutions per minute.	Fuel consumption, unblended gasoline.[2]		Hourly fuel consumption in pounds.[1]						Oil consumed, pounds per hour.
			Sea level.	5,000 feet.	Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.	
Liberty	6	1,700	85	85	108	92	76	63	56	54	8.0
Liberty	12	1,700	170	170	216	185	152	125	111	107	16.0
Liberty (supercharged)	12	1,700	(3)	(3)	216	216	216	216	216	200	16.0
Packard	825	1,800	91	91	116	99	82	67	60	58	8.6
Packard	1237	1,800	138	138	175	150	123	102	90	87	13.0
Packard	2025	1,800	230	230	292	250	205	169	150	145	21.6
Wright Hispano	I	1,450	70	70	89	76	63	52	46	44	6.2
Wright Hispano [4]	E-2	1,800	81	81	103	88	73	60	53	51	7.6
Wright Hispano [5]	E-2	2,000	89	89	113	97	80	66	58	56	8.4
Wright Hispano	H	1,800	142	142	180	154	127	104	93	90	12.4
Wright Hispano	H-3	2,000	149	149	189	162	133	110	97	94	14.0
Wright	Radial	1,800	158	158	200	171	141	116	103	99	24.5
Lawrance	3 cyl	1,600	23	23	29	25	20	17	15	14	3.5
Lawrance	R-1	1,600	63	63	80	68	56	46	41	40	9.8
Lawrance	J-1	1,800	90	90	114	98	80	66	59	57	14.0
Le Rhone	C	1,200	50	50	64	55	45	37	33	32	6.4
Le Rhone	J-b	1,200	76	76	96	82	68	56	49	48	9.6
Le Rhone	R	1,350	114	114	144	123	101	84	74	72	14.4
Curtiss	OX-5	1,400	39	39	49	42	34	28	25	24	3.6
Curtiss	C-6	1,750	68	68	86	74	61	50	44	43	6.4
Curtiss (direct)	C-12	2,000	160	160	203	173	143	118	104	101	15.0
Rausie	E-6	1,650	68	68	86	74	61	50	44	43	6.4
Aeromarine	U-8-D	1,600	72	72	92	79	65	53	47	46	6.8
Almen	Barrel	2,000	160	160	203	173	143	118	104	101	15.0
McCook	W-1	1,700	298	298	378	323	266	219	194	188	28.0
McCook	W-2	1,400	426	426	540	462	380	313	278	268	40.0

[1] The hourly fuel consumption for both normal and high compression ratios is assumed to be the same at a given speed, since no changes in carburetor setting are contemplated or are generally necessary. However, with the high ratios, "doped" fuel must be used.

[2] These data apply only to high compression engines which have to be throttled at sea level and up to 7,000 feet to avoid detonation. This fuel consumption is maintained to 7,000 feet. Above 7,000 feet, values are the same as for operation with doped fuel.

[3] The supercharged Liberty does not have to be run throttled, as explained in footnote 2.

[4] Training.

[5] Alert.

Table III.—*Per cent variation in horsepower with altitude at constant engine speed, for normal engines.*[1]

Altitude.	Per cent horsepower.
Sea level	100.0
5,000 feet	83.8
10,000 feet	68.0
15,000 feet	53.7
20,000 feet	40.3
25,000 feet	26.1

[1] Based on average results obtained in the altitude chamber of the Bureau of Standards, 1920, on the Liberty 12, Hispano-Suiza 300, and Hispano-Suiza 180 engines at several speeds. See Engineering Division Report, Serial No. 1232.

Table IV.—*Per cent drop with altitude in speed of engine-propeller unit in flight, for normal engines.*[1]

Altitude.	Per cent revolutions per minute.
Sea level	100.0
5,000 feet	98.5
10,000 feet	95.9
15,000 feet	93.4
20,000 feet	88.8
25,000 feet	83.4

[1] Based on data obtained in flight on eight Liberty 12, four Hispano-Suiza model "H," and one Hispano-Suiza model "E" engines.

Table V.—*Per cent variation in horsepower with altitude, allowing for drop in speed of the engine-propeller unit, for normal engines.*[1]

Altitude.	Per cent horsepower.
Sea level	100.0
5,000 feet	82.5
10,000 feet	65.2
15,000 feet	50.2
20,000 feet	35.8
25,000 feet	21.8

[1] Based on values of Tables III and IV.

Table VI.—*Per cent variation in specific fuel consumption with altitude, for normal engines.*[1]

Altitude.	Per cent specific fuel consumption.
Sea level	100.0
5,000 feet	103.6
10,000 feet	108.0
15,000 feet	115.7
20,000 feet	144.1
25,000 feet	228.5

[1] Based on the results obtained in the Bureau of Standards altitude chamber on the model "H" Hispano-Suiza and the 12-cylinder Liberty engines, each operating at two speeds. See Engineering Division Reports, Serial Nos. 1232 and 1233.

Table VII.—*Per cent variation in hourly fuel consumption with altitude, allowing for drop in speed of the engine-propeller unit, for normal engines.*[1]

Altitude.	Per cent hourly fuel consumption.
Sea level	100.0
5,000 feet	85.5
10,000 feet	70.4
15,000 feet	58.0
20,000 feet	51.4
25,000 feet	49.7

[1] Based on Tables V and VI.

File D 52.45/82. (C. A. S. I. C. 3)

AIR SERVICE INFORMATION CIRCULAR.

(AVIATION.)

CHANGES }
No. 3. }

WAR DEPARTMENT, AIR SERVICE,
June 15, 1922.

Page 5, Table II, sections A and B, and page 6, Table IIa, inclusive, Air Service Information Circular, Volume IV, No. 317, "Method for Estimating Power and Fuel Consumption of Normal Compression Aviation Engines in Flight at Various Altitudes," are changed, by direction of the Chief of Air Service, in accordance with a recommendation of the Engineering Division contained in a letter dated April 27, 1922, as follows:

Page 5, Table II, sections A and B, substitute the following:

TABLE II.—*Estimated full-throttle horsepower at actual revolutions per minute at sea level and various altitudes.*[1]

SECTION A.—NORMAL COMPRESSION RATIOS APPROXIMATELY 5-5.5:1.

Engine and class of service.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower at actual revolutions per minute.[2]					
				Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Training:									
Aeromarine	U-8-D	1,600	560	180	148	117	90	64	39
Curtiss	OX-5	1,400	385	90	74	59	45	32	20
Curtiss	C-6	1,750	450	160	132	104	80	57	35
Lawrance	J-1	1,650	[3] 435	180	148	117	90	64	39
Le Rhone	C	1,200	260	[4] 80	66	52	40	29	17
Le Rhone	J-b	1,200	320	[4] 120	99	78	60	43	26
Liberty [5]	"6"	1,700	635	200	165	130	100	72	44
Packard	825	1,450	555	180	148	117	90	64	39
Rausie	E-6	1,650	550	160	132	104	80	57	35
Wright Hispano	E-2	1,700	475	180	148	117	90	64	39
Wright Hispano	I	1,700	470	180	148	117	90	64	39
Alert:									
Aeromarine	U-8-D	2,000	560	200	165	130	100	72	44
Lawrance	J-1	1,800	[3] 435	[3] 200	165	130	100	72	44
Le Rhone	R	1,350	380	160	132	104	80	57	35
Packard	825	2,000	555	225	186	147	113	81	49
Wright Hispano	E-2	2,000	475	210	173	137	105	75	46
Pursuit:									
Almen	Barrel	2,000	725	[3] 375	309	245	188	134	82
Curtiss	CD-12	2,000	705	375	309	245	188	134	82
Packard	1237	1,800	740	[6] 325	268	212	163	116	71
Wright Hispano	H	1,800	635	310	256	202	156	111	68
Wright Hispano	H-3	1,800	620	315	260	205	158	113	69
Wright Hispano	H-3	2,000	620	350	289	228	176	125	76
Wright	Radial	1,650	[3] 885	[3] 350	289	228	176	125	76
Observation and bombardment:									
Liberty	"12"	1,700	[7] 845	400	330	261	201	143	87
Liberty [8]	"12"	1,700	1,010	400	400	400	400	400	333
McCook	W-1	1,700	1,815	700	578	456	351	250	153
McCook	W-2	1,400	[3] 2,400	[3] 1,000	825	652	502	358	218
Packard	2025	1,800	1,170	540	446	352	271	193	118
Miscellaneous:									
Lawrance	"L" series	1,700	160	55	45	36	28	20	12
Lawrance	Torpedo	1,800	155	55	45	36	28	20	12

[1] Add 10 per cent to power output in making computations for cooling systems. The performance estimates are based on actual tests except in instances where reference is made to footnotes 3 and 4. In most cases, the estimates are lower than the test results to allow for variation between engines, atmospheric variations, etc.
[2] Allowing for drop in engine propeller speed based on average drop observed on numerous tests of Liberty and Wright Hispano engines.
[3] Estimated. (Engines under construction; in most cases no test data or weights are available.)
[4] Rated power. Actual developed power not known.
[5] Equipped with magneto ignition.
[6] Power output obtained from report by Packard Motor Car Co. No engines of this type (with low compression) are planned for production.
[7] Weight is with Zenith U. S. 52 carburetors. With inverted carburetors weight is 860 pounds.
[8] Equipped with General Electric supercharger. Power output assumed constant to 20,000 feet and then to decrease with decrease in density.

(C. A. S. I. C. 3)

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

106374—22

TABLE II.—*Estimated full-throttle horsepower at actual revolutions per minute at sea level and various altitudes*—Con.

SECTION B.—HIGH COMPRESSION RATIO OF 6½:1.

Engine and class of service.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower unblended gasoline.		Horsepower with doped fuel.[9]					
				Sea level.	5,000 feet.[10]	Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Training:											
Aeromarine	U-8-D	1,600	560	147	147	195	161	127	98	70	43
Curtiss	C-6	1,750	450	132	132	175	144	114	88	63	38
Lawrance	J-1	1,650	[11] 435	147	147	195	161	127	98	70	43
Liberty	"6"	1,700	635	162	162	215	177	140	108	77	47
Packard	825	1,450	555	147	147	196	161	127	98	70	43
Wright Hispano	E-2	1,700	475	147	147	195	161	127	98	70	43
Alert:											
Aeromarine	U-8-D	2,000	560	162	162	215	177	140	108	77	47
Lawrance	J-1	1,800	[11] 435	162	162	215	177	140	108	77	47
Packard	825	2,000	555	180	180	240	198	157	121	86	52
Wright-Hispano	E-2	2,000	475	169	169	225	186	147	113	81	49
Pursuit:											
Almen	Barrel	2,000	725	305	305	405	334	264	203	145	88
Curtiss	CD-12	2,000	705	305	305	405	334	264	203	145	88
Packard	1237	1,800	740	263	263	350	289	228	176	125	76
Wright Hispano[12]	H-3	1,800	620	256	256	340	280	221	171	122	74
Wright Hispano[12]	H-3	2,000	620	282	282	375	309	245	188	134	82
Wright	Radial	1,650	[11] 885	286	286	380	313	248	191	136	83
Observation and bombardment:											
Liberty[12]	"12"	1,700	845	338	338	450	371	294	226	161	98
McCook	W-1	1,700	1,815	568	568	755	623	492	379	270	165
McCook	W-2	1,400	[11] 2,400	812	812	1,080	891	704	542	387	235
Packard	2025	1,800	1,170	440	440	585	483	381	294	209	128

[9] Allowing for drop in engine-propeller speed based on average drop observed on numerous tests of Liberty and Wright Hispano engines with normal compression ratios. While tests show that the drop is not quite as great for the high compression ratio, the absolute difference is small enough to be disregarded for the sake of simplicity.

[10] This horsepower is maintained (by throttling) to 7,000 feet. Above 7,000 feet values are the same as for operation with doped fuel.

[11] Estimated.

[12] Increase of sea-level horsepower with 6½:1 compression ratio obtained from actual tests of high compression engines compared with output with 5-5½:1 compression ratios. For the other engines the sea-level horsepower (using doped fuel) was estimated to be 8 per cent greater than the sea-level horsepower with 5-5½:1 compression ratios.

(C. A. S. I. C. 3)

Page 6, Table IIa, substitute the following:

TABLE IIa.—*Estimated full-throttle fuel and oil consumption in pounds per hour at sea level and various altitudes for both normal and high compression ratios.*[1]

Engine and class of service.	Model.	Normal revolutions per minute.	Fuel consumption, unblended gasoline.[2]		Hourly fuel consumption in pounds.[1]						Oil consumed, pounds per hour.
			Sea level.	5,000 feet.	Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.	
Training:											
Aeromarine	U-8-D	1,600	76	76	97	83	68	56	50	48	7.2
Curtiss	OX-5	1,400	(3)	(3)	49	42	34	28	25	24	3.6
Curtiss	C-6	1,750	68	68	86	74	61	50	44	43	6.4
Lawrance	J-1	1,650	81	81	103	88	73	60	53	51	10.8
Le Rhone	C	1,200	(3)	(3)	64	55	45	37	33	32	6.4
Le Rhone	J-b	1,200	(3)	(3)	96	82	68	56	49	48	9.6
Liberty	"6"	1,700	85	85	108	92	76	63	56	54	8.0
Packard	825	1,450	76	76	97	83	68	56	50	48	7.2
Rausie	E-6	1,650	(3)	(3)	86	74	61	50	44	43	6.4
Wright Hispano	E-2	1,700	76	76	97	83	68	56	50	48	7.2
Wright Hispano	I	1,700	(3)	(3)	97	83	68	56	50	48	7.2
Alert:											
Aeromarine	U-8-D	2,000	85	85	108	92	76	63	56	54	8.0
Lawrance	J-1	1,800	90	90	114	98	80	66	59	57	12.0
Le Rhone	R	1,350	(3)	(3)	128	109	90	74	66	64	12.8
Packard	825	2,000	96	96	122	104	86	71	63	61	9.0
Wright Hispano	E-2	2,000	89	89	113	97	80	66	58	56	8.4
Pursuit:											
Almen	Barrel	2,000	160	160	203	173	143	118	104	101	22.5
Curtiss	CD-12	2,000	160	160	203	173	143	118	104	101	15.0
Packard	1237	1,800	138	138	175	150	123	102	90	87	13.0
Wright Hispano	H	1,800	(3)	(3)	167	143	118	97	86	83	12.4
Wright Hispano	H-3	1,800	134	134	170	145	120	99	87	84	12.6
Wright Hispano	H-3	2,000	149	149	189	162	133	110	97	94	14.0
Wright	Radial	1,650	158	158	200	171	141	116	103	99	21.0
Observation and bombardment:											
Liberty	"12"	1,700	170	170	216	185	152	125	111	107	16.0
Liberty (supercharged)	"12"	1,700	(4)	(4)	216	216	216	216	216	200	16.0
McCook	W-1	1,700	298	298	378	323	266	219	194	188	28.0
McCook	W-2	1,400	426	426	540	462	380	313	278	268	40.0
Packard	2025	1,800	230	230	292	250	205	169	150	145	21.6
Miscellaneous:											
Lawrance	"L" Series	1,700	(3)	(3)	31	27	22	18	16	15	3.3
Lawrance	Torpedo	1,800	(3)	(3)	31	27	22	18	16	15	3.3

[1] These data apply only to high-compression engines which have to be throttled at sea level and up to 7,000 feet to avoid detonation. This fuel consumption is maintained to 7,000 feet. Above 7,000 feet, values are the same as for operation with doped fuel.

[2] The hourly fuel consumption for both normal and high-compression ratios is assumed to be the same at a given speed, since no changes in carburetor setting are contemplated or are generally necessary. However, with the high ratios "doped" fuel must be used.

[3] These engines will not be equipped with high-compression pistons, and consequently these data are omitted.

[4] The supercharged Liberty does not have to be run throttled, as explained in footnote 3.

(C. A. S. I. C. 3)

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1922

File D 52.33 / 200 McCOOK FIELD REPORT, SERIAL No.1749

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV March 15, 1922 No. 318

EFFECT ON VARIATION IN LOAD FACTOR ON STRUCTURAL WEIGHT OF WINGS

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio,
September 13, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

EFFECT OF VARIATION IN LOAD FACTOR ON STRUCTURAL WEIGHT OF WINGS.

INTRODUCTION.

The object of this investigation is to determine the effect of variations in load factor or useful load upon the sizes and weights of the various parts of the wings.

Assuming the formulas used by the Air Service for the solution of lift trusses and the design of spars and struts to be correct, a definite relationship is established between the useful load and the sizes of members so that it is possible for the designer to predict the resultant sizes and weights due to variations in the useful load.

It is shown that with the present methods of design the area of the spar is of first importance and that within certain limits the area of the routed spars may be arranged without regard to the effect upon the moment of inertia.

The investigation is conducted throughout in terms of the load factor, but by a simple computation the result of changing the weight of useful load instead of the load factor may be estimated.

Two sets of computations are made, one for the R. A. F.-15 section and one for the U. S. A.-27 section, with the wing areas, aspect ratios, gap chord ratio, stagger and weights the same in each case, thus showing any difference in effect on a thin wing and on a moderately thick one.

Consideration of the subject will show that the weight of the covering will not be affected by variation in the load factor, and that the weight of the loading and trailing edges, ribs, drag wires, etc., will be subject to little if any change. The main struts and spars will change in weight and the total weight will change in proportion. This study is therefore limited to the lift trusses.

The stresses in a typical lift truss under a load factor of 1 are computed, multiplied by various load factors, trusses designed for the resulting stresses, and the weights compared.

CONCLUSIONS.

1. The area of spars varies directly with the load factor.
2. The area of struts varies with the load factor and the increase in area is at a slightly smaller rate than the increase in load factor.
3. The weights of the lift truss members vary with their respective areas, and therefore increase at a rate slightly less than that of the load factor.
4. In considering changes in design necessitated by changes in useful load it will be on the safe side to assume that the areas and weights of members of the lift trusses vary directly with the per cent increase in the load factor, and for small increases the error will be negligible.
5. If the spars are designed as light as is consistent with good practice, small increases in useful load with the thicker wing sections may be met by decreasing the routing.
6. The structural weight of wings varies with the load factor, but does not increase as rapidly as the load factor.
7. When an increase of useful load is made in an airplane, it is safe to predict that the sizes and weights will increase in proportion, though the design of the members should be checked before the new sizes are given final approval. This prediction should give fairly accurate sizes, but will give weights that are heavier than they are found to be when the design is checked.

ASSUMPTIONS.

1. In this investigation two flight conditions were considered, high incidence and low incidence.
2. The following assumptions were made with respect to the location of the center of pressure, the angle of incidence, and the value of L/D:

U. S. A. 27.

Flight condition.	Angle of incidence.	L/D.	Position of center of pressure.
	°		*Per cent.*
High incidence	16	9.2	27.4
Low incidence	−2	7.8	63.4

R. A. F. 15.

Flight condition.	Angle of incidence.	L/D.	Position of center of pressure.
	°		*Per cent.*
High incidence	12	10.7	29.0
Low incidence	0	8.1	44.3

3. The standard decrease in loading on the wing tips was assumed.
4. The lower wing was assumed to be 86 per cent as efficient as the upper wing in high incidence and 87 per cent as efficient as the upper wing in low incidence, in accordance with division of load between wings as recommended in article 44 of "Structural analysis and design of airplanes."
5. The wing tips were assumed to be square.
6. The spars were assumed to be hinged at the cabane struts.
7. The lift wires were crossed so that their drag effect would relieve the direct stresses in the spars.
8. The weight of the wings was assumed at 1 pound per square foot and the gross wing loading was assumed at 8 pounds per square foot in computing the stresses in the struts and spars. No correction of the stresses was made to allow for the actual weights of each design.
9. The spars were assumed to be at 12 per cent and 67 per cent of the chord.

10. The aerodynamic characteristics assumed for the U. S. A.–27 section were obtained from the wind tunnel tests at Massachusetts Institute of Technology in November, 1920; those for the R. A. F.–15 section were obtained from the wind tunnel test at Massachusetts Institute of Technology in December, 1919.

11. The location of the outer strut, bay 1–2, and cantilever length were determined by the recommended proportions in article 34 of "Structural analysis and design of airplanes."

12. The drag truss was divided into three panels between the cabane and outer struts.

GENERAL DATA.

Weight of airplane, without wings	2,400 lbs.
Total span of wings	31.5 ft.
Gap	68 in.
Chord of both wings	68 in.
Stagger	+13.6 in.
Length of center section, both wings	30 in.
Length of bay, both wings	110 in.
Length of cantilever section, both wings	64 in.
Area of upper wing	178.6 sq. ft.
Area of lower wing	164.4 sq. ft.
Weight of wings	343 lbs.
Distance from leading edge to front spar	8.16 in.
Distance from leading edge to rear spar	45.56 in.

COMPUTATIONS.

1. The stresses, moments, etc., in the lift trusses are computed for a load factor of 1.0 according to the method in Chapter III of "Structural analysis and design of airplanes," the distribution between the front and rear lift trusses effected, and the direct stress in the spars corrected for the drag truss stresses.

2. Multiplying by the various load factors, we have the moments, shears, stresses, etc., as shown in Tables I and II.

3. The spars were designed for both the U. S. A.–27 section and the R. A. F.–15 section for the stresses, moments, etc., resulting at the various load factors, and the sizes and weights are shown in Tables III, IV, V, VI, VII, and VIII, the method in article 174 of "Structural analysis and design of airplanes" being used.

4. The struts were designed for the loads at the different load factors with sizes as shown in Tables IX and X. The method in Article 91, of "Structural analysis and design of airplanes" was used, combined with Euler's formula for pin-ended columns:

$$P=\frac{\pi^2 EI}{L^2} \text{ or } I=\frac{PL^2}{\pi^2 E}$$

Assuming a standard streamline wood strut with a fineness of 4, with L=the length of the strut cross section and D the width.

$$I=.0432LD^3$$

$$\text{As } L=4D$$

$$I=.1728D^4$$

$$A=.730LD=2.92D^2$$

$$A^2=8.53D^4 \text{ and } \frac{A^2}{49.34}=.1728D^4$$

$$\text{Then } I=\frac{A^2}{49.34}$$

$$\text{Then } \frac{A^2}{49.34}=\frac{PL^2}{\pi^2 E} \text{ and } A=.001768\times L\times\sqrt{P}$$

where A=cross sectional area,
L=length of strut, and
P=comp. in strut.

5. Curves were plotted showing the variation of the cross sectional area of the spars in the routed portion in terms of the load factor (see Fig. 1).

6. Curves showing the variation in weight of the spars in terms of the load factor were plotted (see Fig. 2). In computing these weights it was assumed that there would be a 10-inch unrouted length at the strut points, a 12-inch unrouted length at the wing tips, and 5 inches was subtracted from each 12-inch unrouted portion at the wing tips to allow for the taper of the spars at that point. The spars were considered to be of spruce and to weigh 27 pounds per cubic foot.

7. Curves were plotted showing the variation of the cross sectional area of the outer struts in terms of the load factor, as shown in figure 3.

TABLE I.—*U. S. A.–27.*

	Load factor.	Truss.	Load per cent of W.	Lower spars.		Upper spars.					Drag stress.		Maximum direct stress.	
				M_{1L}	M_{1-2L}	M_{1u}	M_{1-2u}	C_u	S_{+1u}	W/1-inch.	First bay.	Second bay.	At strut.	In span.
High incidence	1.0	Combined	1.00	−4,780	+2,890	−5,670	+3,380	−1,362	+265	3.88				
	1.0	F	.72	3,442	2,081	4,082	2,434	−981	191	2.79	−30	+228	−1,011	−753
	1.0	R	.28	1,338	809	1,588	946	−381	74	1.09	−228	−459	−609	−840
	5.0	F	3.60	17,208	10,404	20,412	12,168	−4,903	954	13.97	−150	+1,140	−5,053	−3,763
	5.0	R	1.40	6,692	4,046	7,938	4,732	−1,907	371	5.43	−1,140	−2,295	−3,047	−4,202
	6.0	F	4.32	20,650	12,485	24,494	14,602	−5,884	1,145	16.76	−180	+1,368	−6,064	−4,516
	6.0	R	1.68	8,030	4,855	9,526	5,678	−2,288	445	6.52	−1,368	−2,754	−3,656	−5,042
	7.0	F	5.04	24,091	14,566	28,577	17,035	−6,861	1,336	19.56	−210	+1,596	−7,074	−5,268
	7.0	R	1.96	9,369	5,664	11,113	6,625	−2,670	519	7.60	−1,596	−3,213	−4,266	−5,883
	8.0	F	5.76	27,533	16,646	32,659	19,469	−7,845	1,526	22.35	−240	+1,824	−8,085	−6,021
	8.0	R	2.24	10,707	6,474	12,701	7,571	−3,051	594	8.69	−1,824	−3,672	−4,875	−6,723
	9.0	F	6.48	30,974	18,727	36,742	21,902	−8,826	1,717	25.14	−270	+2,052	−9,096	−6,774
	9.0	R	2.52	12,046	7,283	14,288	8,518	−3,432	668	9.78	−2,052	−4,131	−5,484	−7,563
	10.0	F	7.20	34,416	20,808	40,824	24,336	−9,806	1,908	27.94	−300	+2,280	−10,106	−7,526
	10.0	R	2.80	13,384	8,092	15,876	9,464	−3,811	742	10.86	−2,280	−4,590	−6,094	−8,404
Low incidence.	1.0	Combined	1.000	−4,810	+2,902	−5,624	+3,360	−1,362	+263	3.86				
	1.0	F	.065	313	189	366	218	−89	17	0.25	−251.4	−506.4	−340.4	−595.4
	1.0	R	.935	4,497	2,713	5,258	3,142	−1,273	246	3.61	−28.6	+251.4	−1,301.6	−1,021.6
	4.0	F	.260	1,251	755	1,462	871	−354	68	1.00	−1,006	−2,026	−1,360	−2,380
	4.0	R	3.740	17,989	10,853	21,034	12,566	−5,094	984	14.44	−114	+1,006	−5,208	−4,088
	5.0	F	.325	1,563	943	1,828	1,092	−443	85	1.25	−1,257	−2,532	−1,700	−2,975
	5.0	R	4.675	22,487	13,567	26,292	15,708	−6,367	1,230	18.05	−143	+1,257	−6,510	−5,110
	6.0	F	.390	1,876	1,132	2,193	1,310	−531	103	1.51	−1,508	−3,038	−2,039	−3,569
	6.0	R	5.610	26,984	16,280	31,551	18,850	−7,641	1,475	21.65	−172	+1,508	−7,813	−6,133
	7.0	F	.455	2,189	1,320	2,559	1,529	−620	120	1.76	−1,760	−3,545	−2,380	−4,165
	7.0	R	6.545	31,481	18,994	36,809	21,991	−8,914	1,721	25.26	−200	+1,760	−9,114	−7,154

TABLE II.—*R. A. F.-15.*

Load factor.		Truss.	Load, per cent of W.	Lower spars.		Upper spars.								
											Drag stress.		Maximum direct stress.	
				M_{1L}.	M_{1-2L}.	M_{1u}.	M_{1-2u}.	C_u.	S_{+1u}.	W/1 inch.	First bay.	Second bay.	At strut.	In span.
High incidence.	1.0	Combined	1.000	−4,780	+2,890	−5,670	+3,380	−1,362	+ 265	3.88	....	....	....	....
	1.0	F........	.691	3,303	1,997	3,918	2,336	− 941	+ 183	2.68	− 21	+ 224	− 962	− 717
	1.0	R........	.309	1,477	893	1,752	1,044	− 421	+ 82	1.20	− 224	− 451	− 645	− 872
	5.0	F........	3.455	16,515	9,985	19,590	11,678	−4,706	+ 916	13.41	− 105	+1,120	−4,810	−3,585
	5.0	R........	1.545	7,385	4,465	8,760	5,222	−2,104	+ 409	5.99	−1,120	−2,255	−3,225	−4,360
	6.0	F........	4.146	19,818	11,982	23,508	14,013	−5,647	+1,099	16.09	− 126	+1,344	−5,772	−4,302
	6.0	R........	1.854	8,862	5,358	10,512	6,267	−2,525	+ 491	7.19	−1,344	−2,706	−3,870	−5,232
	7.0	F........	4.837	23,121	13,979	27,426	16,349	−6,588	+1,282	18.77	− 147	+1,568	−6,734	−5,019
	7.0	R........	2.163	10,339	6,251	12,264	7,311	−2,946	+ 573	8.39	−1,568	−3,157	−4,515	−6,104
	8.0	F........	5.528	26,424	15,976	31,344	18,685	−7,529	+1,465	21.45	− 168	+1,792	−7,696	−5,736
	8.0	R........	2.472	11,816	7,144	14,016	8,355	−3,367	+ 655	9.59	−1,792	−3,608	−5,160	−6,976
	9.0	F........	6.219	29,727	17,973	36,262	21,020	−8,470	+1,648	24.13	− 189	+2,016	−8,658	−6,453
	9.0	R........	2.781	13,293	8,037	15,768	9,400	−3,788	+ 737	10.79	−2,016	−4,059	−5,805	−7,848
	10.0	F........	6.910	33,030	19,970	39,180	23,356	−9,411	+1,831	26.81	− 210	+2,240	−9,620	−7,170
	10.0	R........	3.090	14,770	8,930	17,520	10,444	−4,209	+ 819	11.99	−2,240	−4,510	−6,450	−8,720
Low incidence.	1.0	Combined	1.000	−4,810	+2,902	−5,624	+3,360	−1,362	+ 263	3.86	....	....	....	....
	1.0	F........	.413	1,987	1,199	2,323	1,388	− 563	+ 109	1.59	+ 22	+ 69	− 541	− 494
	1.0	R........	.587	2,823	1,703	3,301	1,972	− 799	+ 154	2.27	− 69	− 136	− 868	− 935
	4.0	F........	1.652	7,946	4,794	9,291	5,551	−2,250	+ 434	6.38	+ 88	+ 276	−2,164	−1,976
	4.0	R........	2.348	11,294	6,814	13,205	7,889	−3,198	+ 618	9.06	− 276	− 544	−3,472	−3,740
	5.0	F........	2.065	9,933	5,995	11,614	6,938	−2,813	+ 543	7.97	+ 110	+ 345	−2,705	−2,470
	5.0	R........	2.935	14,117	8,517	16,506	9,862	−3,997	+ 772	11.33	− 345	− 680	−4,340	−4,675
	6.0	F........	2.478	11,919	7,191	13,936	8,326	−3,375	+ 652	9.57	+ 132	+ 414	−3,246	−2,964
	6.0	R........	3.522	16,941	10,221	19,808	11,834	−4,797	+ 926	13.59	− 414	− 816	−5,208	−5,610
	7.0	F........	2.891	13,906	8,390	16,259	9,714	−3,938	+ 760	11.16	+ 154	+ 483	−3,787	−3,458
	7.0	R........	4.109	19,764	11,924	23,109	13,806	−5,596	+1,081	15.86	− 483	− 952	−6,076	−6,545

TABLE III.—*U. S. A.-27.*

FRONT UPPER SPAR—HIGH INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section.		Routed.		Factor of safety of design.		Section areas.		Weight in pounds.
	Height.	Width.	Flanges.	Web.	At strut.	In span.	At strut.	In span.	
	Inches.	*Inches.*	*Inches.*	*Inches.*					
6.0	6-1/4	1-1/16	5/16	5/16	12.12	6.00	6.64	2.42	17.5
7.0	6-1/4	1-1/4	3/8	11/32	14.17	6.97	7.81	2.83	20.5
8.0	6-1/4	1-3/8	13/32	3/8	15.57	8.06	8.59	3.28	23.3
9.0	6-1/4	1-1/2	7/16	7/16	16.87	8.95	9.37	3.66	25.9
10.0	6-1/4	1-1/2	1/2	1/2	16.87	10.10	9.37	4.12	28.1

Average area in routed portion=0.407 sq. in./F. S.

TABLE IV.—*U. S. A.-27.*

REAR UPPER SPAR—HIGH INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section.		Routed.		Factor of safety of design.		Section areas.		Weight in pounds.
	Height.	Width.	Flanges.	Web.	At strut.	In span.	At strut.	In span.	
	Inches.	*Inches.*	*Inches.*	*Inches.*					
6.0	5-3/8	31/32	1/4	9/32	19.56	6.00	5.21	1.86	13.5
7.0	5-3/8	1-1/8	5/16	5/16	22.54	7.05	6.05	2.19	15.9
8.0	5-3/8	1-7/32	3/8	11/32	24.40	8.01	6.55	2.50	17.8
9.0	5-3/8	1-9/32	7/16	3/8	25.65	8.98	6.88	2.81	19.6
10.0	5-3/8	1-1/2	1/2	3/8	29.82	10.06	8.06	3.14	22.2

Average area in routed portion=0.312 sq. in./F. S

TABLE V.—*U. S. A.-27.*

REAR UPPER SPAR—LOW INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section.		Routed.		Factor of safety of design.		Section areas.		Weight in pounds.
	Height.	Width.	Flanges.	Web.	At strut.	In span.	At strut.	In span.	
	Inches.	*Inches.*	*Inches.*	*Inches.*					
4.0	5 3/8	7/8	11/16	3/8	6.14	4.01	4.70	2.42	15.9
5.0	5 3/8	1 1/8	1/2	7/16	7.78	5.03	6.05	3.04	20.0
6.0	5 3/8	1 3/16	11/16	1/2	8.22	6.00	6.38	3.63	23.2
7.0	5 3/8	1 1/4	11/16	5/8	8.54	6.98	6.72	4.22	26.3

Average area in routed portion = .6046 sq. in./F. S.

TABLE VI.—*R. A. F.-15.*

FRONT UPPER SPAR—HIGH INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section.		Routed.		Factor of safety. of design.		Section areas.		Weight in pounds.
	Height.	Width.	Flanges	Web.	At strut.	In span.	At strut.	In span.	
	Inches.	*Inches.*	*Inches.*	*Inches.*					
5.0	3 7/8	1 13/16	9/16	3/8	9.19	4.99	6.90	3.03	20.7
6.0	3 7/8	1 15/16	5/8	13/32	9.95	5.99	7.51	3.65	24.2
7.0	3 7/8	2 1/32	5/8	13/32	10.42	7.03	7.87	4.31	27.8
8.0	3 7/8	2 3/32	5/8	3/8	11.64	8.00	8.84	4.91	31.5
9.0	3 7/8	2 11/32	11/16	13/16	12.55	9.01	9.56	5.55	35.3
10.0	3 7/8	2 17/32	5/8	3/8	13.25	10.00	10.11	6.16	38.8

Average area in routed portion = .613 sq. in./F. S.

TABLE VII.—*R. A. F.-15.*

REAR UPPER SPAR.—HIGH INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section.		Routed.		Factor of safety of design.		Section areas.		Weight in pounds.
	Height.	Width.	Flanges.	Web.	At strut.	In span.	At strut.	In span.	
	Inches.	*Inches.*	*Inches.*	*Inches.*					
5.0	3	1 1/4	11/16	1/4	10.00	4.96	4.50	2.81	17.6
6.0	3	1 1/2	3/4	3/8	10.90	5.97	4.88	3.38	20.7
7.0	3	1 7/8	13/16	13/32	12.51	7.05	5.63	3.99	24.3
8.0	3	2	7/8	15/32	13.27	8.02	6.00	4.56	27.4
9.0	3	2 1/4	15/16	7/8	14.81	8.98	6.75	5.12	30.8
10.0	3	2 3/8	1	11/16	15.70	10.00	7.13	5.69	33.9

Average area in routed portion = .568 sq. in./F. S.

TABLE VIII.—*R. A. F.-15.*

REAR UPPER SPAR.—LOW INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section.		Routed.		Factor of safety of design.		Section areas.		Weight in pounds.
	Height.	Width.	Flanges.	Web.	At strut.	In span.	At strut.	In span.	
	Inches.	*Inches.*	*Inches.*	*Inches.*					
4.0	3	1 1/2	11/16	3/4	5.66	4.04	4.50	3.28	19.9
5.0	3	1 7/8	23/32	7/8	7.06	4.98	5.62	4.06	24.7
6.0	3	2 1/4	3/4	1 1/32	8.40	6.00	6.75	4.92	29.9
7.0	3	2 1/2	13/16	1 1/4	9.31	7.05	7.50	5.78	34.7

Average area in routed portion = .8174 sq. in./F. S.

TABLE IX.—*U. S. A.–27.*

OUTER STRUTS.

Load factor.	Strut.	High incidence.				Low incidence.			
		Load per cent of L. truss.	Compression in strut.	Length.	Areas in square inches.	Load per cent of L. truss.	Compression in strut.	Length.	Areas in square inches.
			Pounds.				*Pounds.*		
1	Combined....	1.00	−386	....	....	1.000	−389	....	....
1	F............	.72	278	61.75	....	.065	25	61.75	....
1	R............	.28	108	62.62	....	.935	364	62.62	....
4	F............	2.88	1,112	61.75	3.64	.260	101	61.75	1.10
4	R............	1.12	432	62.62	2.30	3.740	1,455	62.62	4.23
5	F............	3.60	1,390	61.75	4.07	.325	126	61.75	1.23
5	R............	1.40	540	62.62	2.57	4.675	1,819	62.62	4.72
6	F............	4.32	1,668	61.75	4.46	.390	152	61.75	1.35
6	R............	1.68	648	62.62	2.82	5.610	2,182	62.62	5.18
7	F............	5.04	1,945	61.75	4.81	.455	177	61.75	1.45
7	R............	1.96	757	62.62	3.04	6.545	2,546	62.62	5.59
8	F............	5.76	2,223	61.75	5.15	....	....	....	....
8	R............	2.24	865	62.62	3.23	....	....	....	....
9	F............	6.48	2,501	61.75	5.46	....	....	....	....
9	R............	2.52	973	62.62	3.45	....	....	....	....
10	F............	7.20	2,779	61.75	5.76	....	....	....	....
10	R............	2.80	1,081	62.62	3.64	....	....	....	....

TABLE X.—*R. A. F.–15.*

OUTER STRUTS.

Load factor.	Strut.	High incidence.				Low incidence.			
		Load per cent of L. truss.	Compression in strut.	Length.	Areas in square inches.	Load per cent of L. truss.	Compression in strut.	Length.	Areas in square inches.
			Pounds.				*Pounds.*		
1	Combined....	1.000	−386	....	....	1.000	−389	....	....
1	F............	.691	−267	64⅛	....	.413	161	64⅛	....
1	R............	.309	119	65	....	.587	228	65	....
4	F............	2.764	1,067	64⅛	3.71	1.652	643	64⅛	2.88
4	R............	1.236	477	65	2.51	2.348	913	65	3.47
5	F............	3.455	1,334	64⅛	4.14	2.065	803	64⅛	3.22
5	R............	1.545	596	65	2.80	2.935	1,142	65	3.88
6	F............	4.146	1,600	64⅛	4.54	2.478	964	64⅛	3.52
6	R............	1.854	716	65	3.07	3.522	1,370	65	4.26
7	F............	4.837	1,867	64⅛	4.90	2.891	1,125	64⅛	3.80
7	R............	2.163	835	65	3.32	4.109	1,598	65	4.60
8	F............	5.528	2,134	64⅛	5.25	....	....	....	....
8	R............	2.472	954	65	3.55	....	....	....	....
9	F............	6.219	2,400	64⅛	5.56	....	....	....	....
9	R............	2.781	1,073	65	3.76	....	....	....	....
10	F............	6.910	2,667	64⅛	5.86	....	....	....	....
10	R............	3.090	1,193	65	3.97	....	....	....	....

TABLE XI.—*Different designs for the rear upper spar of the U. S. A.–27 wing at 10 F. S.*

HIGH INCIDENCE CONDITIONS.

Unrouted section.		Routed portion.		Factor of safety of design.		Moment of inertia.		Cross-section areas.		Area ratio.	Weight of spar in pounds.	Deflection of spar in Bay 1–2.
Height.	Width.	Flanges.	Web.	At strut.	In span.	At strut.	In span.	At strut.	In span.			
Inches.	*Inches.*	*Inches.*	*Inches.*									
5⅜	2 1/16	7/16	¼	45.40	9.92	30.00	14.31	12.43	3.15	0.253	25.9	0.389
5⅜	1½	½	⅜	29.82	10.06	19.44	11.59	8.06	3.14	.390	22.2	.480
5⅜	1	21/32	7/16	20.20	10.00	12.96	9.82	5.38	3.09	.574	19.7	.567
5⅜	¾	¾	½	15.16	10.07	9.72	8.51	4.03	3.06	.758	18.4	.653
5⅜	39/64	(1)	(1)	12.34	10.10	7.90	7.90	3.28	3.28	1.000	18.8	.704

[1] No routing.

Area ratio is the ratio of the area of the routed section to that of the unrouted section.

DISCUSSION.

1. The characteristics of the spars designed, listed in Tables III, IV, V, VI, VII, and VIII, show that the area varies directly as the load factor.

2. It will be observed that the weight of the spar varies with the load factor, but not directly with it, as the curves shown in figure 2 take the form $Ax + By = K$. For this particular case, K is undoubtedly the excess area added at the strut points and compression ribs to provide sufficient area for the fittings, to transfer stresses from the ribs, struts, and wires to the spars and to each other, and to stiffen the spars for drag bending. Doubling the load will not double the weight of the spar, though the error in any case is on the safe side, and for small increases in the load factor the error would be so small as to be negligible.

3. The deflection of a spar with constant load and span varies inversely as the moment of inertia, so that an unrouted spar shows greater deflection for a given load than a routed spar of the same area and center height.

4. While the computations made during this investigation have not been as comprehensive in regard to the effect on the F. S. of variations in the moment of inertia as might be desired, they indicate that for a given load and with constant area and center height small variations in the moment of inertia have little if any effect upon the F. S.; and that with constant load, constant span, constant area of the routed portion and center height the moment of inertia may vary at will with little effect upon the F. S., so long as the ratio of the area of the routed portion to the area of the unrouted portion remains between 50 per cent and 80 per cent. However, the characteristics of a spar, a typical case being listed in Table XI, would indicate that as the area ratio approaches 80 per cent the best spar in regard to minimum weight is obtained.

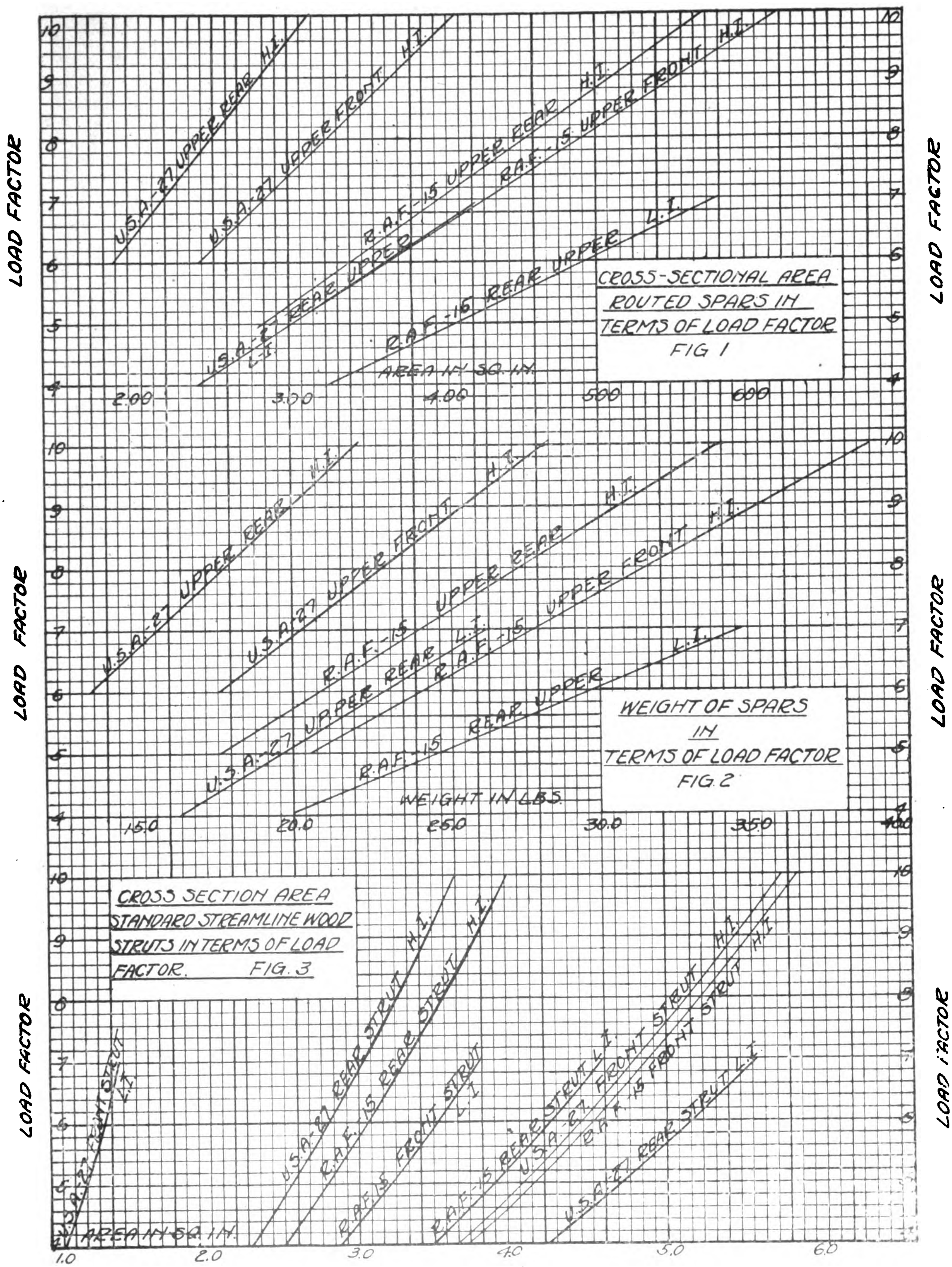
5. In many cases, more especially with the thicker wing sections, when it is desired to amend a design for small increases in useful load, the area of the spar can be increased by decreasing the routing up to a point where the ratio of the area of the routed portion to that of the unrouted portion equals 75 per cent to 80 per cent, thus keeping the spar as light as possible and effecting a saving in the redesign of ribs, fittings, etc.

6. According to the formula for struts, the area varies with the length and with the square root of the load.

7. The curves for the area in terms of the load factor (see fig. 3) show that with the length constant the curve for the area in terms of the load factor is nearly a straight line.

8. If the area of a strut with constant length be increased in proportion to the load factor, the error will be on the safe side in any case, and for small increases in the load factor the error will be negligible.

9. The curves in figure 2 show that the U. S. A.–27 section has lighter spars than the R. A. F.–15 section, and the curves in figure 3 show that the U. S. A.–27 section has a lighter front strut, while the R. A. F.–15 section has a lighter rear strut, due to the difference in center of pressure travel. However, computations will show that the two struts with the R. A. F.–15 section are but very little lighter than those with the U. S. A.–27 section at the load factors of design for pursuit airplanes. With the thicker wing section, the ribs and compression struts would be heavier, but the difference in weight would be small, as it would be due mostly to increased web area.. Because of the greater spar height in the U. S. A.–27 section it is possible, in spite of the increased center of pressure travel, to design spars so much lighter than with the R. A. F.–15 section as to overcome the increased weights due to heavier struts, ribs, and compression struts and to effect a considerable saving in the structural weight of the wings.


LOAD FACTOR
U.S.A.-27 UPPER REAR H.I.
U.S.A.-27 UPPER FRONT H.I.
R.A.F.-15 UPPER REAR H.I.
R.A.F.-15 UPPER FRONT H.I.
U.S.A.-27 REAR UPPER L.I.
R.A.F.-15 REAR UPPER L.I.
CROSS-SECTIONAL AREA
ROUTED SPARS IN
TERMS OF LOAD FACTOR
FIG 1
AREA IN SQ. IN.
2.00
3.00
4.00
500
600
U.S.A.-27 UPPER REAR H.I.
U.S.A.-27 UPPER FRONT H.I.
R.A.F.-15 UPPER REAR H.I.
U.S.A.-27 UPPER REAR L.I.
R.A.F.-15 UPPER FRONT H.I.
R.A.F.-15 REAR UPPER L.I.
WEIGHT OF SPARS
IN
TERMS OF LOAD FACTOR
FIG. 2
WEIGHT IN LBS.
15.0
20.0
250
30.0
350
400
CROSS SECTION AREA
STANDARD STREAMLINE WOOD
STRUTS IN TERMS OF LOAD
FACTOR. FIG. 3
U.S.A.-27 FRONT STRUT L.I.
U.S.A.-27 REAR STRUT H.I.
R.A.F.-15 REAR STRUT H.I.
R.A.F.-15 FRONT STRUT L.I.
R.A.F.-15 REAR STRUT L.I.
U.S.A.-27 FRONT STRUT H.I.
R.A.F.-15 FRONT STRUT H.I.
U.S.A.-27 REAR STRUT L.I.
AREA IN SQ. IN.
1.0
2.0
3.0
4.0
5.0
6.0

Figs. 1, 2, and 3

Library

[redacted]
File D 11.3/26

McCOOK FIELD REPORT, SERIAL No. 175[illegible]

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922. | No. 319

REPORT ON THE ELIMINATION OF DETONATION WITH "AVIATION" AND "MOTOR" GASOLINE BY THE ADDITION OF XYLIDINE, ORTHO-TOLUIDINE, BENZOL, AND GENERAL MOTORS ANTI-KNOCK No. 1

(POWER PLANT SECTION REPORT)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
September 14, 1921

7

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INDEX.

REPORT ON THE ELIMINATION OF DETONATION WITH "AVIATION" AND "MOTOR" GASOLINE BY THE ADDITION OF XYLIDINE, ORTHO-TOLUIDINE, BENZOL, AND GENERAL MOTORS ANTI-KNOCK NO. 1.

OBJECT OF TEST.

The object of these tests was to investigate the effectiveness of various antiknock compounds in eliminating detonation with aviation and low test gasoline.

RESULTS OF TEST.

The following table shows the percentages of antiknock compounds required to eliminate detonation with aviation and low test gasoline with various compression ratios, as determined by this test:

Fuel.	Compression radio.	Engine.	Ortho-toluidine (per cent).	Xylidine (per cent).	Benzol (per cent).	General Motors Anti-knock No. 1.
Aviation gasoline.	6.7:1	Single-cylinder Liberty engine.	5.5	5.0	45.0	9.0
	5.4:1	Single and six cylinder Liberty engine.	2.25	1.75	18.0	3.0
	5.3:1	Hispano model "H".	2.25	....	22	....
Low test gasoline.	6.7:1	Single-cylinder Liberty engine.	[1] 10.0	[1] 9.5	[1] 60.0	[1] 16.0
	5.4:1	Single and six cylinder Liberty engine.	[1] 7.0 [2] 4.5	[1] 7.0	[1] 35.0	[1] 10.5
	5.3:1	Hispano model "H".	[2] 5.0	....	[2] 37.0	....

[1] Low test gasoline of specific gravity 0.744 at 15° C.
[2] Low test gasoline of specific gravity 0.730 at 15° C.

CONCLUSIONS.

Xylidine appears to be the most effective of the antiknock compounds tested, as regards amount required to eliminate detonation. The highest mean effective pressures were obtained using benzol as the antiknock agent with aviation gasoline.

METHOD OF TEST.

Place, McCook Field.

Date, August 7, 1920–February 15, 1921.

Test engineer, George M. Paulson.

The results of tests which have been conducted on the single-cylinder Liberty engine to determine the effect of various antiknock mixtures under full-throttle operation are covered in a preliminary Engineering Division Report, Serial Number 1711. Since full-throttle operation on the single-cylinder engine gave much higher indicated mean effective pressures than are obtained in multicylinder engines, it was desired to investigate the effectiveness of these antiknock mixtures with the engine throttled to give indicated pressures corresponding to those obtained in service engines. It was also desired to determine the effectiveness of these antiknock mixtures with standard service type multicylinder engines. This test was undertaken to provide such data.

The antiknock substances used were xylidine, ortho-toluidine, General Motors Anti-Knock No. 1 and "Commercial" 90 per cent benzol. Xylidine and ortho-toluidine are coal-tar products homologous to aniline and belonging to the amine series. General Motors Anti-Knock No. 1 consists of homologues of aniline belonging to the amine series, mixed with a small proportion of benzol to insure miscibility with gasoline. Commercial xylidine purchased from the Cincinnati Chemical Works, Cincinnati, Ohio, was used on this test. The other fuels used were as follows:

Ortho-toluidine:
- 50 per cent ortho-toluidine.
- 50 per cent aniline.

Anti-Knock No. 1:
- 70 per cent aromatic amines.
- 30 per cent "Commercial" 90 per cent benzol.

Trioxyalene (see distillation curve figure 1):
- 80 per cent low test gasoline.
- 20 per cent sulphuric ether.

Benzol, "Commercial" 90 per cent (see distillation curve figure 1).

"Aviation" and "Low Test" (Motor) gasolines, War Department Specifications 2-40 and 2-41 (see distillation curves, figure 1).

The low test gasoline of specific gravity 0.744 is about as low as could be accepted under the above specifications.

These tests were conducted on a single-cylinder Liberty engine with compression ratios of 5.4:1 and 6.7:1 and on standard Liberty six-cylinder and 300-horsepower Hispano-Suiza engines. Runs were made with mixtures of aviation and low-test gasolines with ortho-toluidine, xylidine, benzol, and General Motors Anti-Knock No. 1. A few runs with trioxyalene mixtures were also made. During some of the runs 1 per cent to 3 per cent of benzol was added to the ortho-toluidine mixtures to obtain complete miscibility. All mixtures were proportioned by volume.

The Liberty cylinder used had two extra spark plug bosses under the valves. It was mounted on a universal crank case (described in Air Service Information Circular Vol. I, No. 47), coupled to an electric dynamometer, the reaction of which was weighed on a Toledo springless scale. Two standard A. C. plugs were used in the positions under the valves for all the runs except a few with the Midgley indicator. To obtain the indicator cards showing pronounced detonation, plugs were fitted in one of the regular Liberty plug positions and in the position under the exhaust valve. A Zenith carburetor with fixed setting and magneto ignition with a maximum possible advance of 45° were used. The fuel consumption was measured by means of a 2,000 cubic centimeter glass tube graduated in divisions of 10 cubic centimeters, which was used to supply the fuel. The revolutions of the engine were obtained from a revolution counter connected direct to the engine, and were held constant at approximately

1,700 revolutions per minute for all the runs. During each run, readings of the engine revolutions, the brake load, water temperatures in and out, carburetor air temperatures and spark advance were taken. Data tables incorporating the results of these runs are included on pages 4 to 8.

The following runs were made:

RUNS WITH SINGLE-CYLINDER LIBERTY ENGINE 6.7 : 1 COMPRESSION RATIO.

Run No. 1, engine throttled,[1] using aviation and low test gasoline.

Run No. 2, engine throttled, using aviation and low test gasoline with ortho-toluidine, xylidine, and benzol.

Run No. 3, full-throttle operation, using mixtures of trioxyalene and aviation gasoline with ortho-toluidine, xylidine, and benzol.

Run No. 10, engine throttled, using aviation and low test gasoline with General Motors Anti-Knock No. 1.

RUNS WITH SINGLE-CYLINDER LIBERTY ENGINE, 5.4 : 1 COMPRESSION RATIO.

Run No. 6 full-throttle and throttled operation, with aviation gasoline mixtures with ortho-toluidine and xylidine.

Run No. 7, engine throttled, using low test gasoline mixtures with ortho-toluidine and xylidine.

Run No. 8, engine throttled, using aviation and low test gasoline with benzol.

Run No. 9, engine throttled, using aviation and low test gasoline with General Motors Anti-Knock No. 1.

RUNS WITH STANDARD MULTICYLINDER ENGINES.

Run No. 4, Liberty six-cylinder engine, 5.4 : 1 compression ratio, using aviation and low test gasoline with ortho-toluidine and benzol.

Run No. 5, 300-horsepower Hispano-Suiza engine, 5.3 : 1 compression ratio, using aviation and low test gasoline with ortho-toluidine.

During all of the single-cylinder runs, as little time as possible was lost between runs of different mixtures which lasted from two to three minutes, the mixtures being changed without stopping the engine. The "throttled" runs were made with the throttle set to give the same indicated mean effective pressures as would be obtained in multicylinder service engines of approximately the same compression ratio. These indicated mean effective pressures were computed from the brake mean effective pressures and mechanical efficiencies obtained on tests of several multicylinder engines, and were 146 pounds per square inch for 6.7 : 1 compression ratio, and 134 pounds per square inch for 5.4 : 1 compression ratio. The multicylinder engine tests with 6.7 : 1 compression ratio on which these pressures are based, were conducted with a 50 per cent benzol and aviation gasoline mixture as fuel. The corresponding brake loads for the single-cylinder runs were computed, using 80 per cent as the mechanical efficiency of the Liberty single-cylinder engine. (See Mechanical Efficiency Determination in Air Service Information Circular, Vol. II, No. 199.)

The Liberty six-cylinder and Hispano-Suiza 300-horsepower engines used had normal compression ratios of 5.4 : 1 and 5.3 : 1, respectively, and were run on a Sprague electric dynamometer. Particular attention was given to the spark adjustment, which was arranged so that a maximum advance of about 42° could be obtained. Two fuel tanks were used, one for a fixed fuel mixture which would not detonate, and the other for the mixture to be tested. These tanks were connected so that the flow could be switched rapidly from one to the other. The water temperatures were kept as nearly constant as possible at 170° F. in the Liberty engine and 150° F. in the Hispano-Suiza engine. The oil temperatures were also held as nearly constant as possible.

Early in the tests it was found that the spark setting had a very marked effect on detonation, and it was therefore found necessary to vary the spark advance for each fuel in order to determine whether or not detonation had been eliminated with the spark set at the point for maximum power. To do this, it was necessary to distinguish between the power drop due to excessive spark advance and that due to detonation. It was assumed that detonation was completely eliminated if, as the spark was advanced, a drop in power was obtained before detonation could be heard. With each mixture, as the spark was advanced, the amount of advance, in degrees, was noted for best power, for the point at which detonation was heard, and the point at which a drop in power was obtained. The mixtures recommended are generally those at which a drop in power due to spark advance could be obtained before severe detonation set in.

A Midgley indicator was set up on the single-cylinder Liberty engine with 6.7:1 compression ratio in order to check the results of the runs and to learn as much as possible about the combustion of the different fuel mixtures and the cylinder pressures obtained. The Midgley indicator shown in figures 3, 4, and 5 consists of three main parts—a pressure element, an indicator unit, and a timing device. The pressure element screws into a spark plug boss in the cylinder, and by means of a piston exposed to the cylinder pressure rocks a small concave mirror about a horizontal axis. This concave mirror catches a beam of light from a point source in the indicator unit and reflects it back in the indicator unit to an octagonal prism, the faces of which are mirrors, and which is synchronized to revolve about a vertical axis at one-eighth of engine speed. The revolving mirrors catch the beam of light from the pressure element mirror and reflect it to the ground glass shown in position in figure 5, on which the beam traces a pressure-time card, the beam transversing the ground glass from left to right once for each revolution of the engine. The timing device shown in the foreground of figure 4 is driven at engine speed, and consists of a distributor, cam, and solenoid. The distributor synchronizes the motor in the indicator unit driving the revolving mirrors with the engine revolutions. The solenoid in conjunction with the cam serves to operate a shutter at the light source and to intensify the light by increased voltage for two revolutions of the engine.

The pressure-time cards were photographed by means of a special film adapter constructed for the tests. The indicator unit and film adapter are shown in figure 3. By pressing a button operating the solenoid and cam an exposure of the film could be made for two revolutions or a complete cycle of engine events.

[1] In this report the word "throttled" indicates that the engine was throttled to give indicated M. E. P.'s equal to those obtained in multicylinder engines as explained above, with ortho-toluidine.

ANALYSIS.

Throughout the test xylidine was found to be the most effective antiknock substance of those tested. While the ortho-toluidine mixture was found to be almost as effective, it did not mix thoroughly with gasoline at low temperatures without a slight addition of benzol. The General Motors Anti-Knock No. 1 gave no trouble in mixing, but to eliminate detonation was required in larger percentages than either xylidine or ortho-toluidine. In all cases the best power was obtained with the engine detonating slightly. The highest mean effective pressures were obtained with mixtures of benzol and aviation gasoline. Almost as high mean effective pressures were obtained, however, with any of the antidetonating compounds mixed in the recommended proportions. The detonation could be made more severe or diminished by advancing or retarding the spark from the best power position, as is shown in some of the indicator cards. The results of the dynamometer runs are shown in the tables of date, pages 4 to 8.

In using the Midgley indicator it was desired to obtain pressure-time cards showing the effect on detonation of variations in the percentages of antiknock mixtures. A compression ratio of 6.7 : 1 was used, and all cards were taken at 1,700 revolutions per minute. In order to be sure that a card representative of average conditions in the cylinder was obtained, three exposures for a complete cycle were made on each film. Due to the double surfaces on one of the mirrors in the indicator, for each exposure one heavy and one light diagram were obtained. The upper diagram (see fig. 2) shows the occurrence of cycle events on one of the benzol cards (see fig. 6). Inertia of some of the indicator parts may be responsible for some of the waves obtained in the indicator diagrams, but the smooth waves due to this cause are easily distinguished from the sharp irregularities due to detonation.

The cards showing best the effect of variations in antiknock percentages and spark advance were obtained under full-throttle conditions and are shown in figures 7, 8, 9, 10, and 11. The slight amount of detonation shown by the sharp irregularities of the expansion lines in figures 7 and 10 is not sufficient to reduce the power delivery of the engine. Detonation such as is shown in figures 8, 11, 12, and 13 is heard as violent "pinking," and generally after a few minutes' running develops into preignition. The most violent detonation of any of the cards was obtained with trioxyalene, at part throttle, figure 13, and was due to the ether content of the fuel. This fuel, compared with other fuels, would allow very little spark advance without detonating violently, giving best power with about 25° advance. Figures 14, 15, 16, and 17 were taken with the throttle and spark set for best power without detonation, and show how the possible brake mean effective pressures with detonation eliminated vary with varying percentages of antiknock. Figure 18 was obtained with a mixture of low-test gasoline and Anti-Knock No. 1, and shows almost as good power results as were obtained from any other mixtures.

It was found that spark-plug positions considerably affected the cards obtained. When using the two plugs under the valves, preignition was obtained apparently without any signs of passing through a stage of detonation, but only with full throttle. As soon as either one of the standard Liberty plug positions was used, detonation could readily be obtained, with less than full throttle. The effect upon flame propagation of using one or two plugs is shown in figures 20 and 21. In both figures the brake mean effective pressure and revolutions per minute are the same, the spark being advanced sufficiently with the one plug to bring the power up to that obtained with two plugs. It should be noted that the rise in pressure is slower with one plug than with two. Figure 19 shows several exposures taken at the instant that preignition became so violent that the engine quickly decelerated from a speed of 1,700 revolutions per minute to less than 1,000 revolutions per minute. The effect of preignition was watched on several occasions, using the ground glass, and it was seen that as preignition developed the "burn" or line of pressure rise of the indicator card advanced rapidly relative to the engine top dead center, until the area on one side of the dead center of the card was almost equal to that on the other side, at which point the pounding of the engine became very severe and the engine was quickly brought to a stop. This card and all other cards obtained show maximum pressures very little higher than the maximum pressures obtained on the cards taken under the best power conditions. Even with the most pronounced detonation and preignition the maximum pressures seem to be about the same as those obtained with best power conditions.

The indicator was carefully calibrated with a Crosby pressure gauge calibrator. A pressure-volume card shown in figure 2 was constructed from one of the best power pressure-time cards obtained with 90 per cent benzol as fuel, figure 6, and the indicated mean effective pressure was obtained by means of a planimeter. The upper dead center on this card was located by taking a card at normal speed of the engine with the spark cut out while the exposure was made so that the curve obtained was of the compression and expansion of the charge without combustion, the dead center being approximately the mid point of the peak of the curve. A very close check of the indicated mean effective pressure with benzol figured from power and friction runs was obtained in this manner. The highest brake mean effective pressure obtained during the tests was 150.4 pounds per square inch, obtained with a mixture of 70 per cent benzol and aviation gasoline, during a run taking indicator cards. Taking the mechanical efficiency of the single cylinder on the universal engine as 80 per cent (as determined in single-cylinder tests), the indicated mean effective pressure obtained on this card would be 188 pounds per square inch. Assuming that this indicated mean effective pressure could be obtained in a multicylinder engine having a mechanical efficiency of 90 per cent, a brake mean effective pressure of well over 160 pounds per square inch would be possible.

In conclusion, it is believed that the percentages of the various antiknock compounds as determined by these tests are sufficiently liberal so that no trouble from detonation would be obtained in service engines using these percentages with normal spark settings. The possibilities of obtaining unusually high mean effective pressures by means of high compression and antidetonating compounds are worthy of further study.

RUN NO. 1.

Single cylinder Liberty engine—6.7:1 compression ratio—Throttle set to give 146 pounds per square inch indicated mean effective pressure with 50 per cent benzol mixture[1]—Aviation and low test gasoline mixtures with ortho-toluidine.

Per cent ortho-toluidine.	Revolutions per minute.	Brake load (pounds).	B. H. P.	Corrected—		Carburetor air temperature (° F.).	Spark setting (degrees).		
				B. M. E. P. (pounds per square inch).	I. M. E. P. (pounds per square inch).		Best power.	Detonation.	Power drop.
Aviation gasoline mixtures.									
4.0	1,690	79.50	33.6	116.8	146.0	56	28	36	38
4.5	1,700	79.75	33.9	117.2	146.5	54	28	36	40
5.0	1,700	79.25	33.69	116.5	145.6	53	28	40	38
5.5	1,700	78.50	33.36	115.4	144.2	53	28	40	40
Low test gasoline mixtures.									
1.5* 7.0	1,704	73.75	31.41	108.4	135.5	51	28	32	32
2.0* 7.5	1,720	74.00	31.82	108.7	135.9	52	28	32	36
2.0* 8.0	1,690	73.62	31.11	108.2	135.3	52	28	32	36
2.5* 9.0	1,710	75.50	32.28	110.9	138.7	57	28	32	36
3.0* 10.0	1,690	76.73	32.43	112.8	141.0	62	28	40	38

* Per cent benzol added to obtain miscibility. Barometer, 29.15 in. Hg.

[1] Multicylinder engine tests on which throttle settings for indicated mean effective pressures are based, were run with 50 per cent benzol mixture as fuel.

Carburetor settings for all single-cylinder runs:
Choke, 40 mm.
Main jet, 25.1 pt. per hr.
Comp. jet, 33.8 pt. per hr.

RUN NO. 2.

Single-cylinder Liberty engine—6.7:1 compression ratio—Throttle set to give 146 pounds per square inch indicated mean effective pressure with 50 per cent benzol mixture[1]—Aviation and low test gasoline mixtures with (R) ortho-toluidine (X) xylidine and (B) benzol.

Fuel mixture (per cent).	Revolutions per minute.	Brake load (pounds).	B. H. P.	Corrected—		Carburetor air temperature (° F.).	Spark setting (degrees).		
				B. M. E. P. (pounds per square inch).	I. M. E. P. (pounds per square inch.)		Best power.	Detonation.	Power drop.
Aviation gasoline mixtures. Barometer 29.13 in. Hg.									
1.0* 5.0 R	1,700	78.0	33.15	114.7	143.4	54	28	32	36
1.0* 5.5 R	1,700	79.0	33.57	116.2	145.2	53	32	36	36
4.0 X	1,700	78.12	33.20	114.9	143.6	56	28	32	40
4.5 X	1,700	79.50	33.79	116.9	146.1	56	28	32	40
5.0 X	1,690	79.75	33.70	117.3	146.6	54	32	36	36
5.5 X	1,706	79.75	34.02	117.3	146.6	56	32	37	36
Low test gasoline mixtures.									
9.0 X	1,710	77.00	32.92	113.2	141.5	58	32	36	40
9.5 X	1,700	77.75	33.04	114.3	142.9	59	32	37	36
Barometer changed to 29.05 in. Hg.									
10.0 X	1,680	74.50	31.29	109.8	137.3	65	32	40	36
Aviation gasoline mixtures.									
40.0 B	1,700	78.50	33.36	115.8	144.8	63	28	36	36
45.0 B	1,690	80.00	33.80	117.9	147.4	64	28	40	36
Low test gasoline mixtures.									
55.0 B	1,700	79.50	33.79	117.2	146.5	64	32	36	36
60.0 B	1,690	79.75	33.70	117.6	147.0	64	32	40	36

* Per cent benzol added to obtain miscibility.

[1] Multicylinder engine tests on which throttle settings for indicated mean effective pressures are based, were run with 50 per cent benzol mixture as fuel.

RUN NO. 3.

Single-cylinder Liberty engine—6.7 : 1 compression ratio—Various fuel mixtures, full-throttle operation—(T) Tri-oxylene, (R) ortho-toluidine, (X) xylidine, (B) benzol, (AG) aviation gasoline.

Fuel mixture (per cent).	Revolutions per minute.	Brake load (pounds).	B. H. P.	Corrected— B. M. E. P. (pounds per square inch).	Corrected— I. M. E. P. (pounds per square inch).	Carburetor air temperature (° F.).	Spark setting (degrees). Best power.	Spark setting (degrees). Detonation.	Spark setting (degrees). Power drop.
Barometer 28.90 in. Hg.									
100 T	1,690	74.0	31.27	109.7	137.1	61	14	24	24
100 T	1,770	76.5	33.85	113.4	141.8	63	14	24	24
3 R 95 T	1,680	99.0	41.58	146.8	183.5	57	32	40	36
Barometer changed to 28.95 in. Hg.									
50 AG 50 B	1,680	97.25	40.85	143.9	179.9	54	32	....	....
95 T 5 X	1,680	98.00	41.16	145.0	181.2	54	28	....	....
93.5 T 6.5 X	1,670	98.00	40.91	145.0	181.2	53	32	....	....
50 T 50 B	1,630	98.75	41.72	146.1	182.6	52	32	....	....
40 T 60 B	1,680	99.75	41.90	147.6	184.5	52	32	....	....

RUN NO. 4.

Liberty six-cylinder engine—Compression ratio, 5.4 : 1—Aviation and low test gasoline mixtures with (R) ortho-toluidine and (B) benzol.

Per cent dope.	Revolutions per minute.	Actual— Brake load (pounds).	Actual— B. H. P.	Corrected— H. P.	Corrected— B. M. E. P. (pounds per square inch).	Water temperature (° F.): In.	Water temperature (° F.): Out.	Carburetor air temperature (° F.).	Spark setting (degrees). Best power.	Spark setting (degrees). Detonation.	Spark setting (degrees). Power drop.
Aviation gasoline mixtures. Barometer, 28.85 in. Hg.											
*	1,720	368.5	211.2	219.1	122.4	150	162	63	29	....	....
3.5 R	1,730	360.0	207.6	215.3	119.5	147	180	63	28	34	31
3.0 R	1,710	364.5	207.7	215.4	121.1	140	172	63	28	34	31
2.5 R	1,710	363.5	207.1	214.8	120.8	159	170	63	28	34	31
*	1,710	364.5	207.7	215.4	121.1	166	175	63	28	....	....
Barometer changed to 29.05 in. Hg.											
*	1,720	372.5	213.6	220.0	122.8	151	165	49	29	....	....
2.0 R	1,700	369.0	209.1	215.4	121.7	160	173	49	28	30	32
1.5 R	1,700	363.0	205.7	211.9	119.7	166	178	47	26	26	31
2.0 R	1,710	368.0	209.7	216.0	121.4	170	179	47	27	31	35
Aviation gasoline mixtures.											
*	1,710	369.0	210.3	216.4	121.6	179	170	52	27	....	....
4 R	1,720	357.0	204.7	210.6	117.6	175	164	50	24	34	34
4.5 R	1,710	360.0	205.2	211.1	118.6	165	154	53	27	None.	34
3.5 R	1,720	357.0	204.7	210.6	117.6	173	160	45	22	29	31
Low test gasoline mixtures.											
*	1,710	375.0	213.7	219.8	123.5	178	167	45	26	....	....
25 B	1,710	350.0	199.5	205.2	115.3	174	157	44	26	23	26
20 B	1,700	335.0	189.8	195.2	110.3	170	156	44	26	26	29
30 B	1,710	341.0	194.3	199.8	112.3	178	164	48	26	29	34
Aviation gasoline mixtures.											
15 B	1,700	364.5	206.5	212.4	120.1	176	164	48	27	34	36

* Run on main tank, 5 per cent ortho-toluidine in aviation gasoline. Barometer, 29.09 in. Hg.

Carburetor setting:

Chokes, $1\frac{3}{16}$ inches.

Main jets, 49.

Comp. jets, 52.

RUN NO. 5.

300-horsepower Hispano-Suiza engine—Compression ratio, 5.3:1.

Per cent dope.	Revolutions per minute.	Actual— Brake load (pounds).	Actual— B. H. P.	Corrected— H. P.	Corrected— B. M. E. P. (pounds per square inch).	Water temperature (°F.). In.	Water temperature (°F.). Out	Carburetor air temperature (°F.).	Spark setting (degrees). Best power.	Spark setting (degrees). Detonation.	Spark setting (degrees). Power drop.
Aviation gasoline mixtures with ortho-toluidine. Barometer, 29.29 in. Hg.											
*	1,800	540.5	324.2	332.9	129.3	130	149	54	27	None.	36.5
3	1,810	535.0	322.7	329.6	128.0	132	150	50	31	38.5	36.5
2½	1,820	539.0	327.0	334.1	129.0	130	146	54	27	36.5	33.5
2	1,810	538.0	324.6	331.6	128.8	130	147	57	27	31.0	31.0
1½	1,790	535.0	319.2	326.2	128.0	132	151	59	27	27.0	31.0
Barometer changed to 29.21 in. Hg.											
2	1,810	538.5	325.0	332.9	129.2	132	148	54	27	31.0	31.0
2¼	1,800	540.0	324.0	331.8	129.6	129	146	52	27	31.0	31.0
2½	1,810	539.0	325.2	333.1	129.3	134	150	52	27	36.5	33.5
Low test gasoline mixtures with ortho-toluidine.											
*	1,810	527.5	318.3	326.0	126.6	132	150	52	27	31.0	31.0
4½	1,790	529.5	316.0	323.6	127.0	135	151	56	27	24.0	31.0
5½	1,800	530.0	318.0	325.7	127.2	133	151	62	27	36.5	33.5

* Run on main tank, 5 per cent ortho-toluidine in aviation gasoline.

RUN NO. 6.

Single-cylinder Liberty engine—5.4:1 compression ratio—Aviation gasoline mixtures with (R) ortho-toluidine and (X) xylidine, full throttle.

Per cent dope.	Revolutions per minute.	Actual— Brake load (pounds).	Actual— B. H. P.	Corrected— B. M. E. P. (pounds per square inch).	Corrected— I. M. E. P. (pounds per square inch).	Carburetor air temperature (°F.).	Spark setting (degrees). Best power.	Spark setting (degrees). Detonation.	Spark setting (degrees). Power drop.
3.0 X	1,710	92.0	39.33	134.7	168.4	53	28½	None.	42½
2.0 X	1,680	91.5	38.43	133.9	167.4	49	28½	None.	28½
1.5 X	1,720	92.1	39.61	134.8	168.5	48	24½	32	30½
1.25 X	1,690	92.5	39.08	135.4	169.3	47	28½	34	36
1.0 X	1,692	92.5	39.12	135.4	169.3	48	23½	32	32
1.75 X	1,690	92.5	39.08	135.4	169.3	48	24½	34	32
2.0 X	1,690	92.75	39.18	135.8	169.8	47	28½	32	32
Throttle set to give 134 pounds per square inch indicated mean effective pressure on aviation gasoline.									
2.0 X	1,692	76.10	32.19	111.4	139.3	50	32	None.	36
1.75 X	1,760	75.75	33.34	110.9	138.6	56	36	None.	39
1.50 X	1,690	75.10	31.74	109.9	137.4	56	32	None.	39
1.50 R	1,690	75.75	32.00	110.9	138.6	52	32	36	36
1.75 R	1,690	75.25	31.80	110.1	137.6	52	36	42	42

Barometer, 29.27 in. Hg.

RUN NO. 7.

Single-cylinder Liberty engine—5.4:1 compression ratio—Throttle set to give 134 pounds per square inch indicated mean effective pressure on aviation gasoline—Low test gasoline mixtures with (X) xylidine and (R) ortho-toluidine.

Per cent dope.	Revolutions per minute.	Actual— Brake load (pounds).	Actual— B. H. P.	Corrected— B. M. E. P. (pounds per square inch).	Corrected— I. M. E. P. (pounds per square inch).	Carburetor air temperature (°F.).	Spark setting (degrees). Best power.	Spark setting (degrees). Detonation.	Spark setting (degrees). Power drop.
Barometer 29.35 in. Hg.									
4.0 X	1,700	70.00	29.75	102.2	127.7	83	24	24	26½
5.0 X	1,710	75.12	32.10	109.7	137.1	75	24½	32	32
5.5 X	1,740	75.37	32.78	110.0	137.5	61	24	32	32
6.0 X	1,660	76.50	31.75	111.7	139.6	62	24	32	32
Barometer changed to 29.37 in. Hg.									
7.0 X	1,656	78.25	32.40	114.1	142.6	62	24	36	32
7.5 X	1,690	77.00	32.53	112.3	140.4	63	32	42	39
1.0 * 7.5 R	1,704	76.62	32.64	111.8	139.7	74	26½	39	34
2.0 * 8.0 R	1,700	77.25	32.83	112.7	140.9	77	30½	None.	36
2.0 * 7.0 R	1,717	77.50	33.26	113.1	141.4	73	27½	36	36

* Per cent benzol added to obtain miscibility.

RUN NO. 8.

Single-cylinder Liberty engine—5.4:1 compression ratio—Throttle set to give 134 pounds per square inch indicated mean effective pressure on aviation gasoline—Aviation and low-test gasoline mixtures with benzol.

Per cent benzol.	Revolutions per minute.	Actual— Brake load (pounds).	Actual— B. H. P.	Corrected— B. M. E. P. (pounds per square inch).	Corrected— I. M. E. P. (pounds per square inch).	Carburetor air temperature (°F.).	Spark setting (degrees). Best power.	Spark setting (degrees). Detonation.	Spark setting (degrees). Power drop.
Aviation gasoline mixtures. Barometer, 29.42 in. Hg.									
12½	1,680	75.0	31.50	109.2	136.5	74	23½	30½	30½
15	1,700	75.5	32.09	109.9	137.4	76	26½	31	31
17½	1,680	75.5	31.71	109.9	137.4	77	26½	37	30½
20	1,690	76.0	32.11	110.7	138.4	76	26½	41½	30½
25	1,710	78.75	33.67	114.7	143.4	74	30½	[1] 42	32
Low test gasoline mixtures. Barometer, 29.36 in. Hg.									
30	1,700	74.75	31.77	109.1	136.4	66	24	30½	30½
35	1,690	74.25	31.36	108.3	135.4	70	24	30½	30½
40	1,710	74.25	31.74	108.3	135.4	72	24	36	30½
45	1,710	73.12	31.26	106.7	133.4	79	24	41½	30½

[1] None.

RUN NO. 9.

Single-cylinder Liberty engine—5.4:1 compression ratio—Throttle set to give 134 pounds per square inch indicated mean effective pressure on aviation gasoline—Aviation and low-test gasoline mixtures with General Motors Anti-Knock No. 1.

Per cent dope.	Revolutions per minute.	Actual—		Corrected—		Carburetor air temperature (°F.).	Spark setting (advance).		
		Brake load (pounds).	B. H. P.	B. M. E. P. (pounds per square inch).	I. M. E. P. (pounds per square inch).		Best power.	Detonation.	Power drop.
Aviation gasoline mixtures. Barometer, 29.27 in. Hg.									
2.0	1,700	75.75	32.20	110.9	138.7	60	39	39	42½
2.5	1,680	76.50	32.13	112.0	140.0	62	36	....	(1)
Barometer changed to 29.20 in. Hg.									
2.5	1,710	77.00	32.92	113.0	141.3	65	33½	41½	41
3.0	1,700	76.50	32.51	112.3	140.4	64	33	[3] 42½	41
3.5	1,690	75.50	31.90	110.8	138.5	65	34	[2] 42½	41
3.0	1,700	76.12	32.35	111.7	139.6	66	34	42½	38½
2.5	1,700	76.12	32.35	111.7	139.6	67	41½	41½	38
Low-test gasoline mixtures.									
10	1,710	76.12	32.54	111.7	139.6	68	25½	41	38½
11	1,700	75.00	31.88	110.1	137.6	69	25½	[3] 42½	38
10.5	1,710	75.75	32.38	111.2	139.0	69	29½	38½	38½
10	1,700	76.37	32.45	112.1	140.1	68	34	41½	38½
10.5	1,690	76.50	32.31	112.3	140.4	68	34	42½	38½

[1] Cam case cover broke. [2] Some. [3] None.

RUN NO. 10.

Single-cylinder Liberty engine—6.7:1 Compression ratio—Throttle set to give 146 pounds per square inch indicated mean effective pressure with 50 per cent benzol mixture [1]—Aviation and low-test gasoline mixtures with General Motors Anti-Knock No. 1.

Per cent dope.	Revolutions per minute.	Actual—		Corrected—		Carburetor air temperature (°F.).	Spark setting (degrees).		
		Brake load (pounds).	B. H. P.	B. M. E. P. (pounds per square inch).	I. M. E. P. (pounds per square inch).		Best power.	Detonation.	Power drop.
Aviation gasoline mixtures.									
7	1,700	78.50	33.36	117.0	146.3	70	29½	28½	34
7½	1,690	81.00	34.22	120.7	150.9	71	29½	29½	34
8	1,700	81.87	34.80	122.0	152.5	71	29½	29½	34
9	1,710	84.00	35.91	125.2	156.5	64	29½	34	34
10	1,690	85.12	35.96	126.8	158.5	65	30½	38	34
Low-test gasoline mixtures.									
15	1,700	82.75	35.17	123.3	154.6	62	30½	26½	34
17½	1,710	86.25	36.87	128.5	160.6	62	30½	40½	38
16	1,690	85.25	36.02	127.0	158.8	64	30½	32	34

Barometer, 26.75 in. Hg.

[1] Multicylinder engine tests on which throttle settings for indicated mean effective pressures are based were run with 50 per cent benzol mixture as fuel.

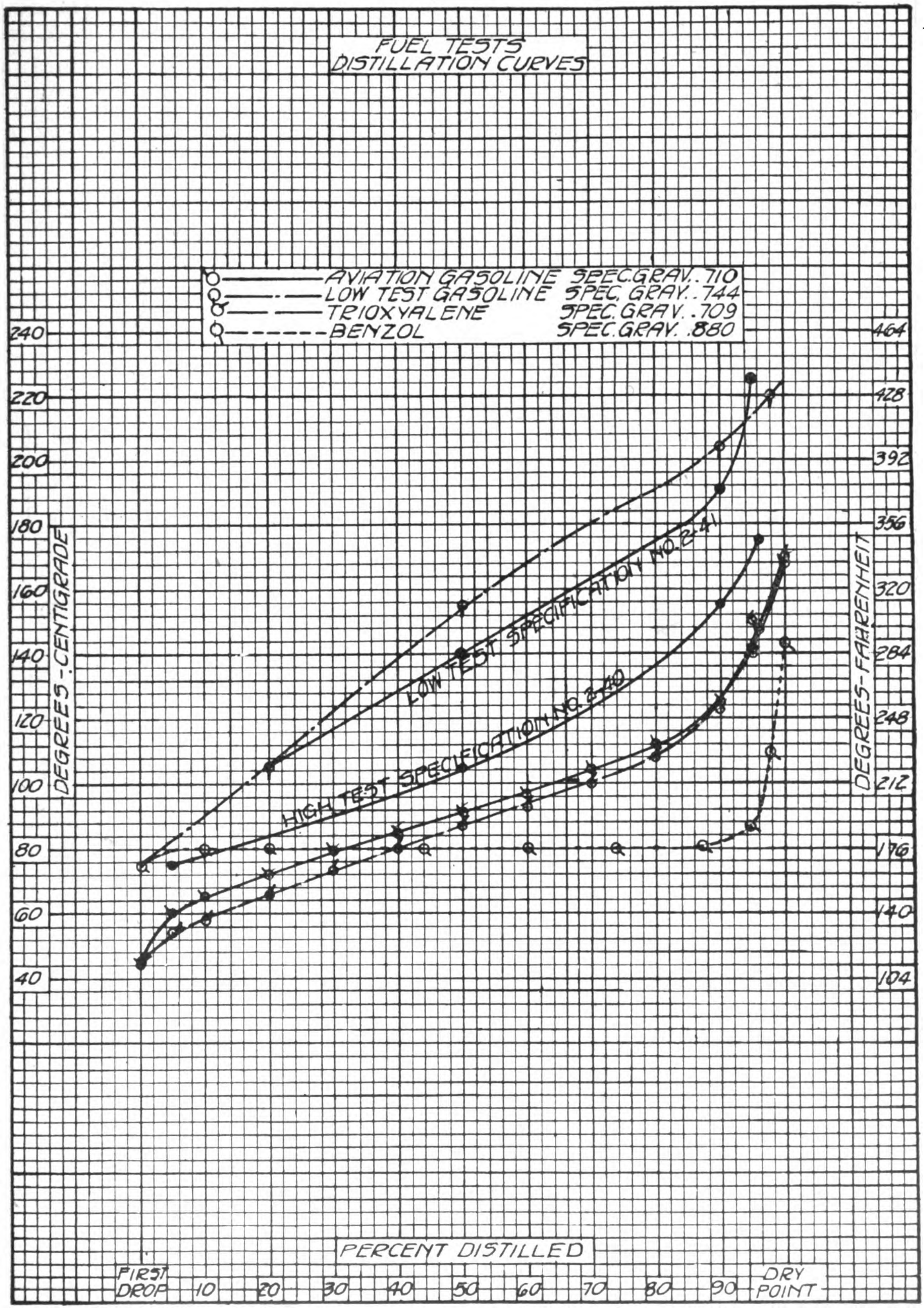

FUEL TESTS
DISTILLATION CURVES
AVIATION GASOLINE SPEC. GRAV. .710
LOW TEST GASOLINE SPEC. GRAV. .744
TRIOXYALENE SPEC. GRAV. .709
BENZOL SPEC. GRAV. .880
LOW TEST SPECIFICATION NO. 2-41
HIGH TEST SPECIFICATION NO. 2-40
DEGREES - CENTIGRADE
DEGREES - FAHRENHEIT
240
220
200
180
160
140
120
100
80
60
40
464
428
392
356
320
284
248
212
176
140
104
PERCENT DISTILLED
FIRST DROP
10
20
30
40
50
60
70
80
90
DRY POINT

FIG. 1.

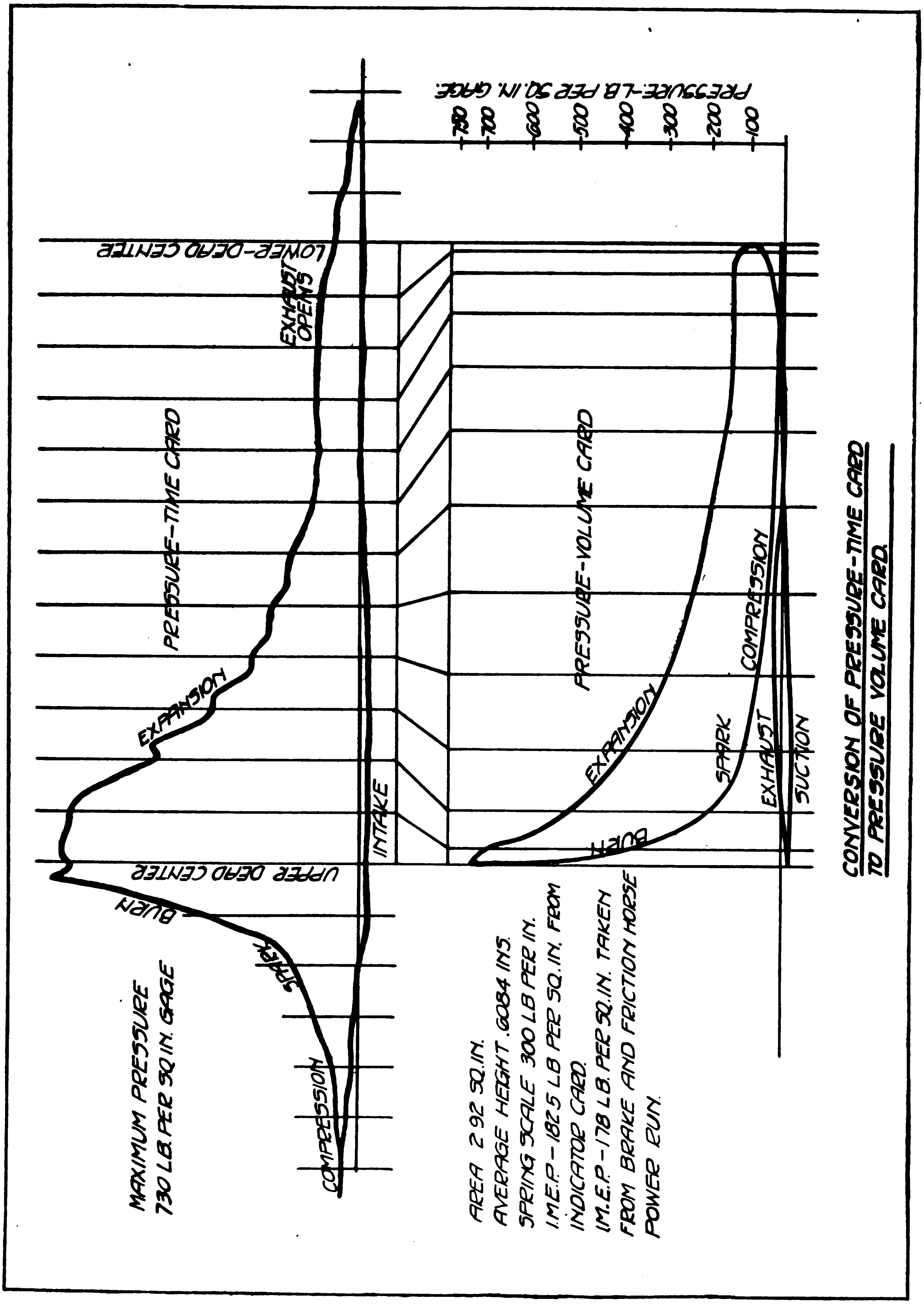

CONVERSION OF PRESSURE-TIME CARD
TO PRESSURE VOLUME CARD.
PRESSURE-TIME CARD
PRESSURE-VOLUME CARD
PRESSURE-LB. PER SQ. IN. GAGE
750
700
600
500
400
300
200
100
LOWER-DEAD CENTER
UPPER DEAD CENTER
EXHAUST OPENS
EXPANSION
BURN
SPARK
COMPRESSION
INTAKE
EXHAUST
SUCTION
MAXIMUM PRESSURE
730 LB. PER SQ. IN. GAGE
AREA 2.92 SQ. IN.
AVERAGE HEIGHT .6084 INS.
SPRING SCALE 300 LB PER IN.
I.M.E.P. - 182.5 LB PER SQ. IN. FROM
INDICATOR CARD.
I.M.E.P. - 178 LB. PER SQ. IN. TAKEN
FROM BRAKE AND FRICTION HORSE
POWER RUN.

FIG. 2.

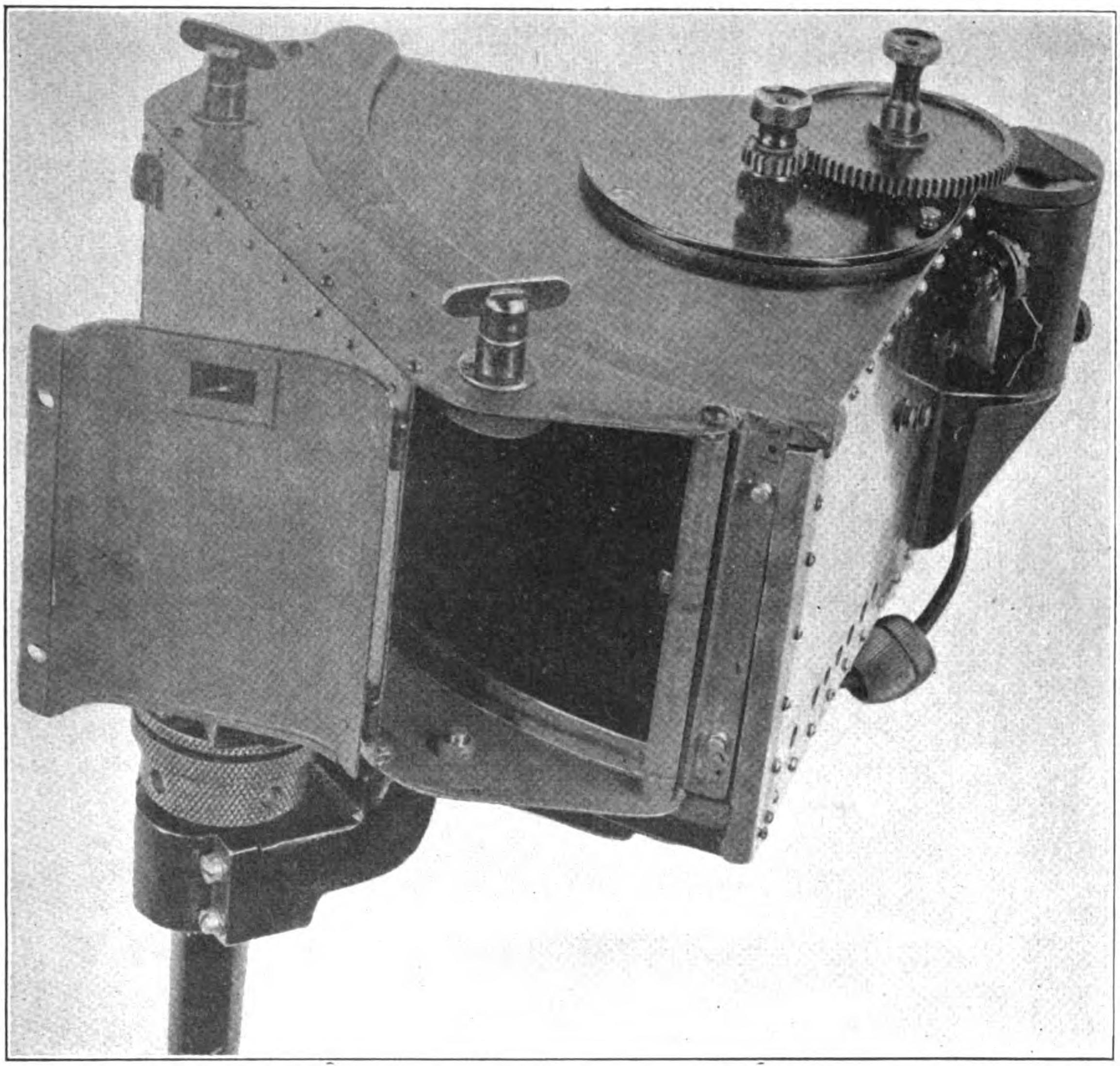


FIG. 3.—Midgley indicator with film adapter.

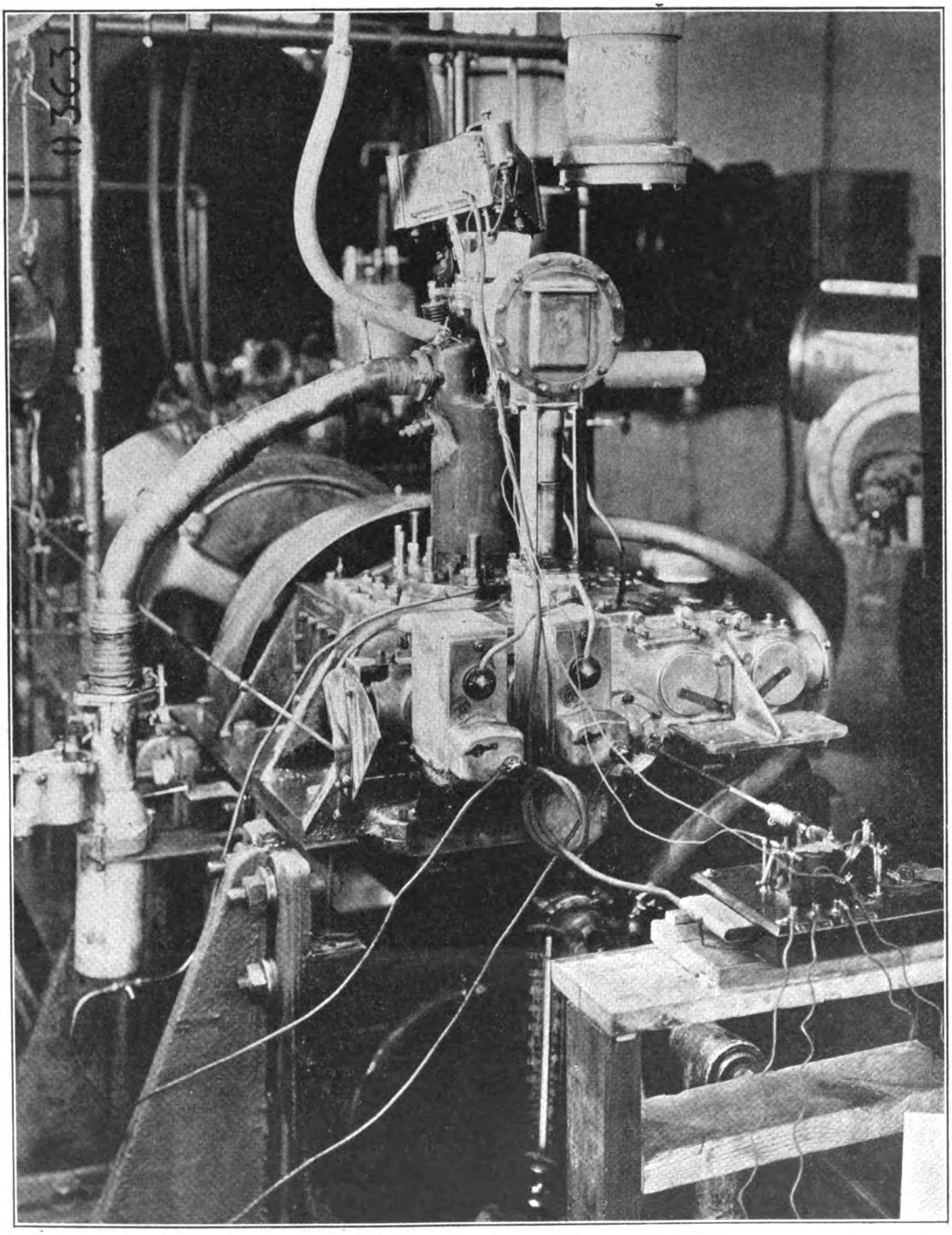


FIG. 4.—Midgley indicator set up on single cylinder Liberty engine.

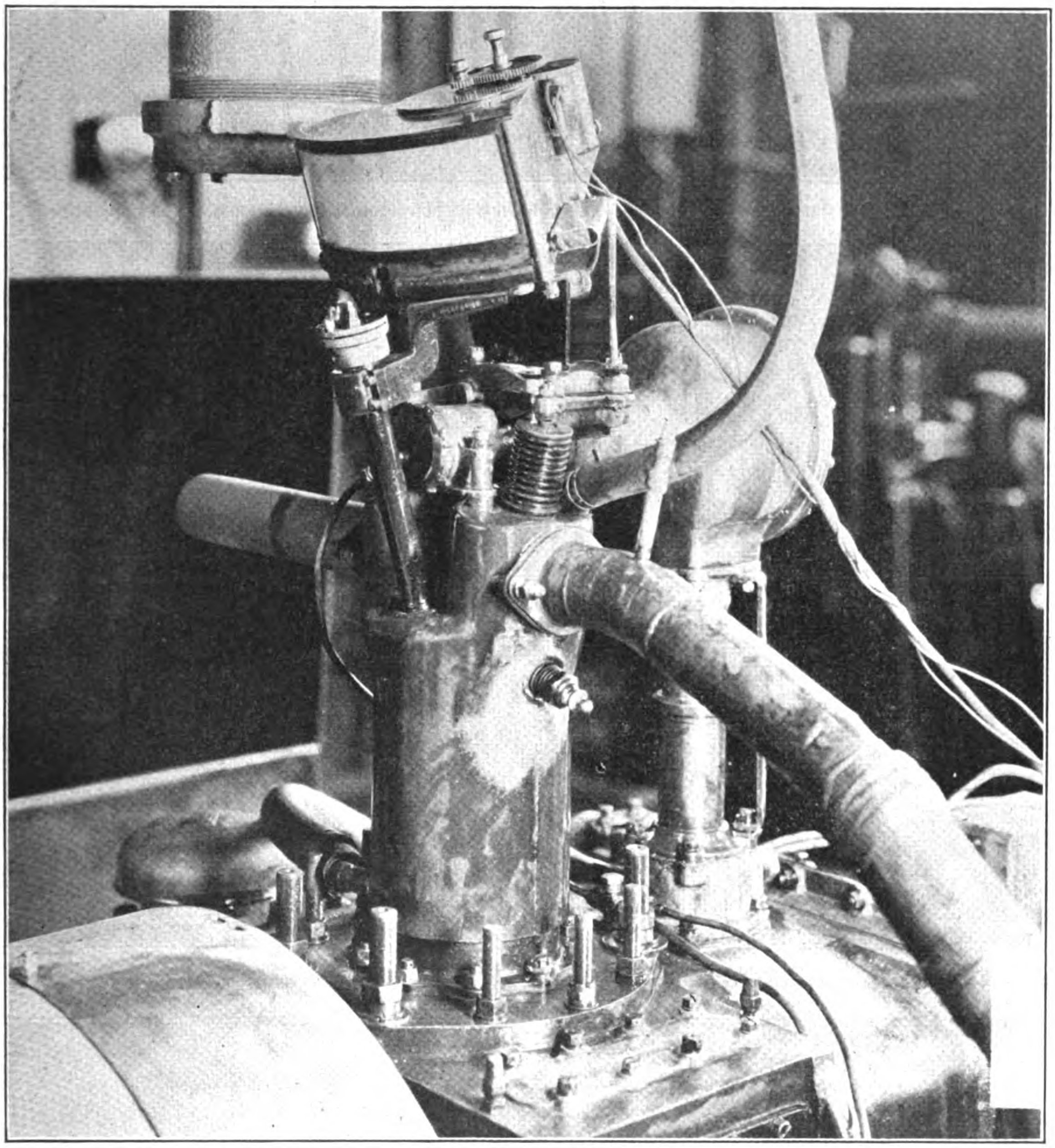


FIG. 5.—Midgley indicator set up on a single cylinder Liberty engine, with ground glass in place.

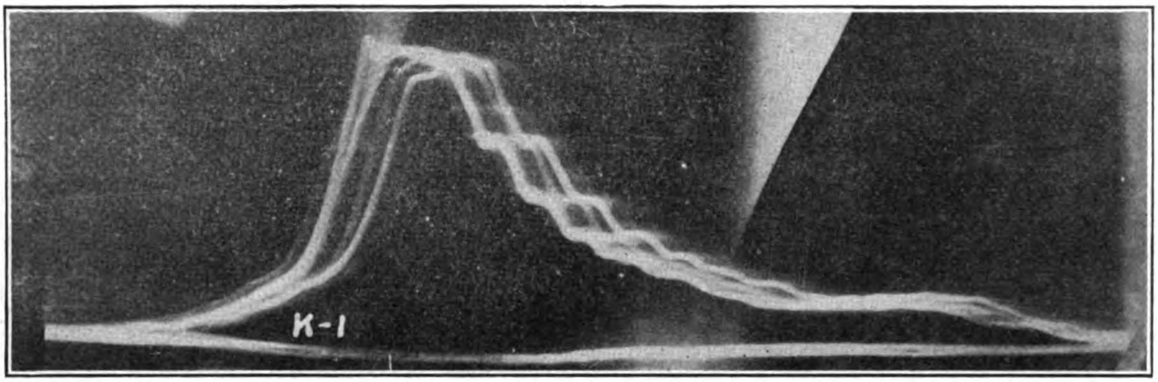


FIG. 6.—K-1.—Benzol. B. M. E. P. 143 pounds per square inch. I. M. E. P. 178.8 pounds per square inch. Spark advance 35°.

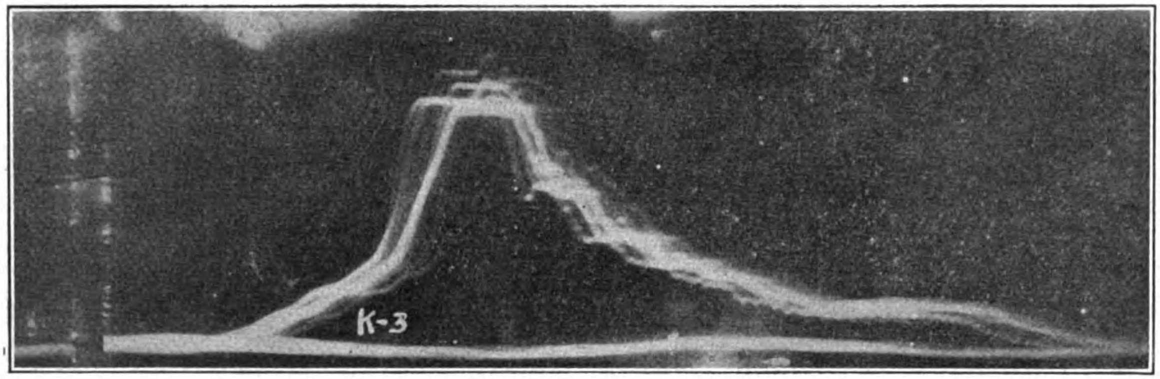


FIG. 7.—K-3.—Aviation gasoline with 9 per cent General Motors Anti-Knock No. 1. B. M. E. P. 138.6 pounds per square inch. Spark advance 30½°.

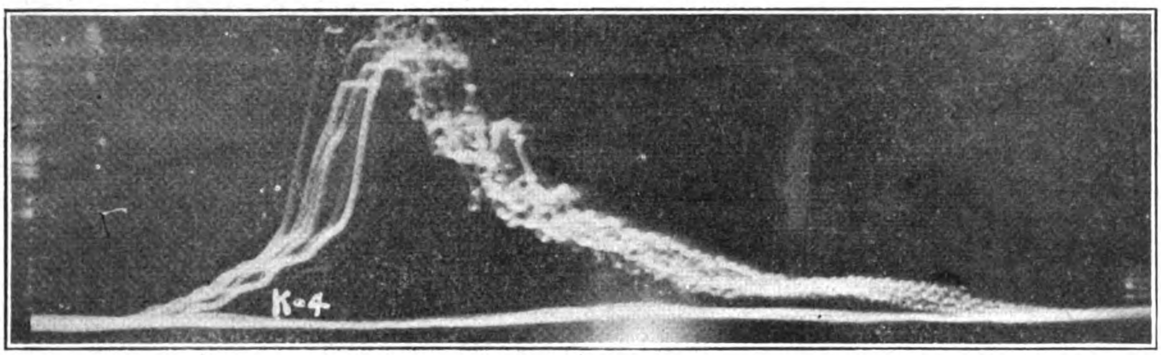


FIG. 8.—K-4.—Aviation gasoline with 7½ per cent General Motors Anti-Knock No. 1. B. M. E. P. 135.7 pounds per square inch. Spark advance 27½°.

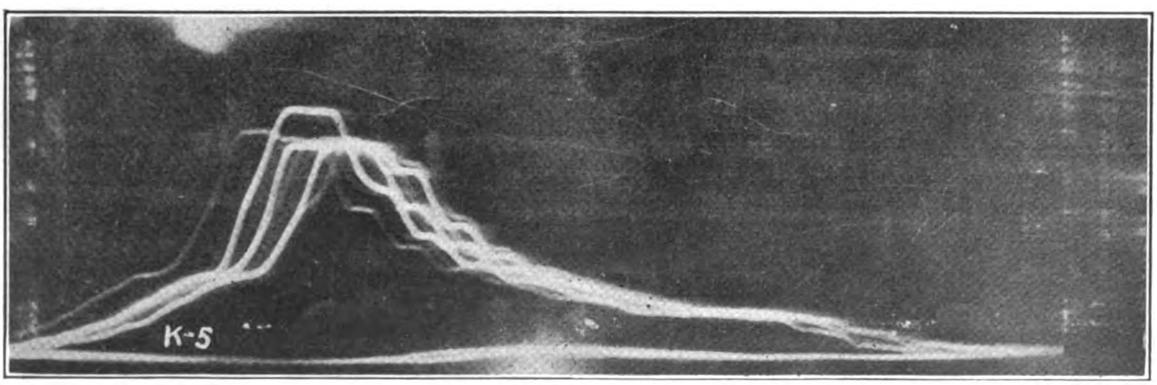


FIG. 9.—K-5.—Aviation gasoline with 7½ per cent General Motors Anti-Knock No. 1. B. M. E. P. 138.6 pounds per square inch. Spark advance 22°.

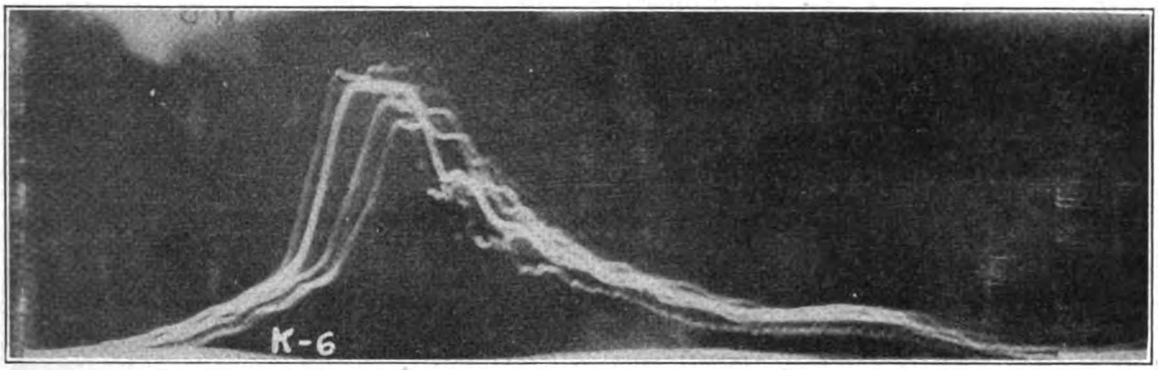


FIG. 10.—K-6.—Aviation gasoline with 10½ per cent General Motors Anti-Knock No. 1. B. M. E. P. 143 pounds per square inch. Spark advance 28½°.

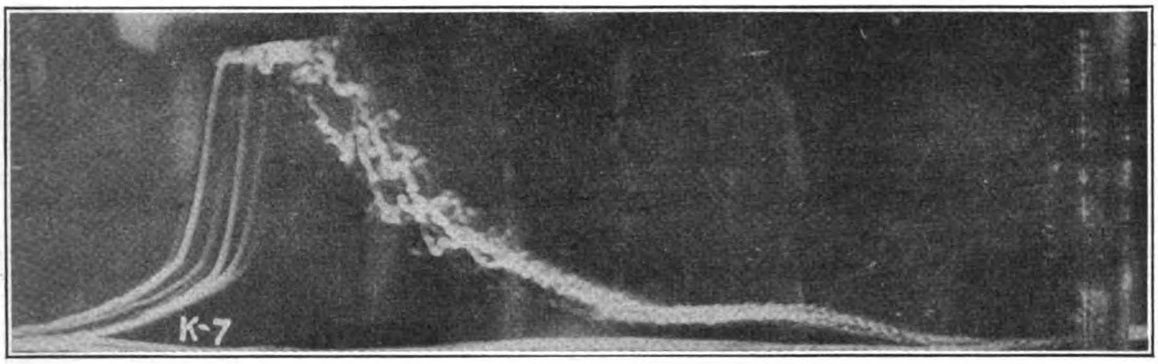


FIG. 11.—K-7.—Aviation gasoline with 10½ per cent General Motors Anti-Knock No. 1. B. M. E. P. 141.6 pounds per square inch. Spark advance 36°.

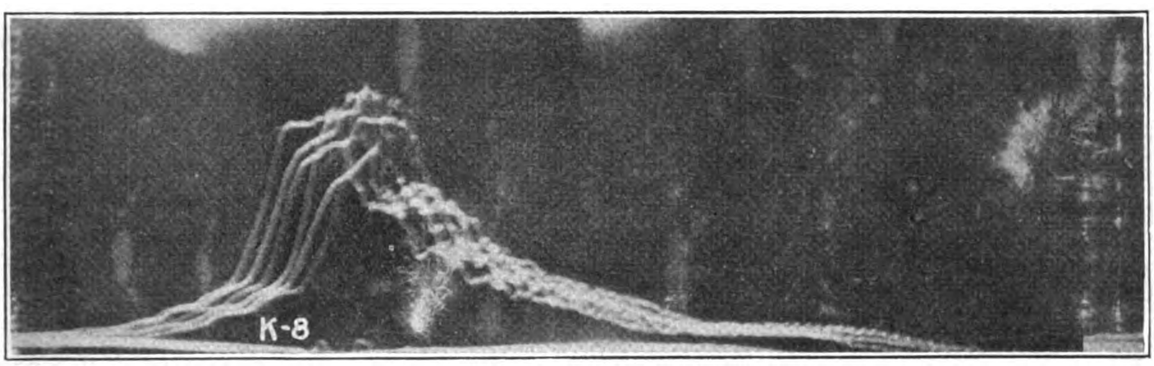


FIG. 12.—K-8.—Aviation gasoline straight. B. M. E. P. 89.95 pounds per square inch. Spark advance 26½°.

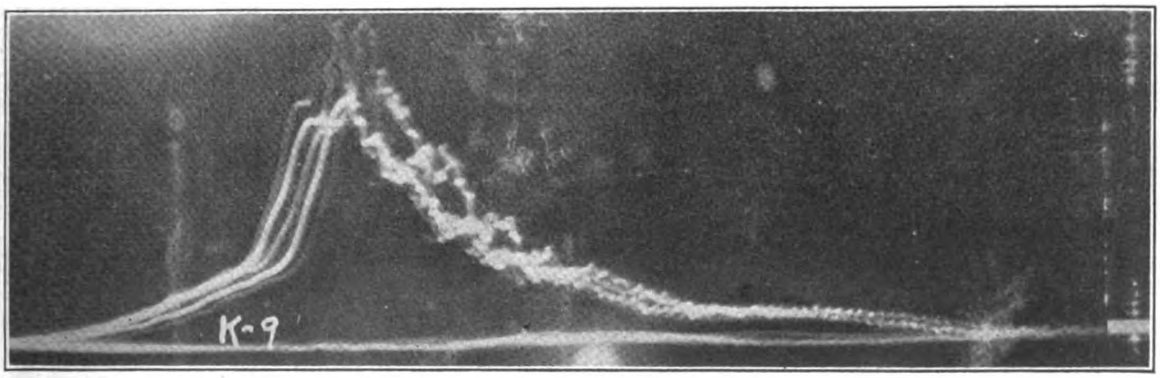


FIG. 13.—K-9.—Trioxyalene (80 per cent low test gas and 20 per cent ether). B. M. E. P. 107.6 pounds per square inch. Spark advance 25°.

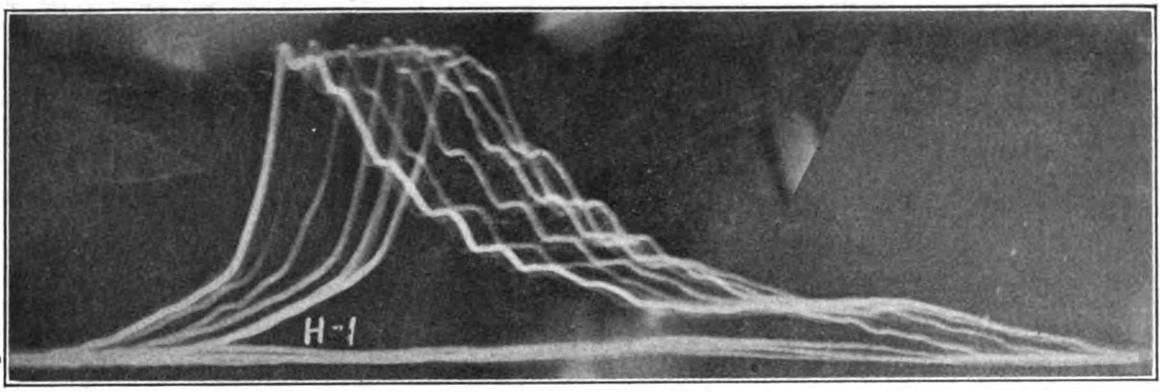


FIG. 14.—H-1.—Aviation gasoline with 10 per cent General Motors Anti-Knock No. 1. Full throttle. B. M. E. P. 145.1 pounds per square inch.

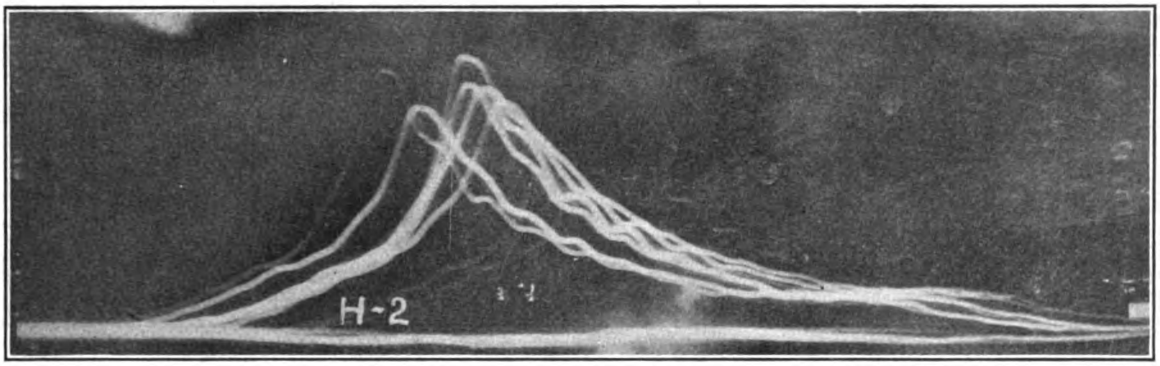


FIG. 15.—H-2.—Aviation gasoline with 7 per cent General Motors Anti-Knock No. 1. B. M. E. P. 133.2 pounds per square inch. Throttled to eliminate detonation.

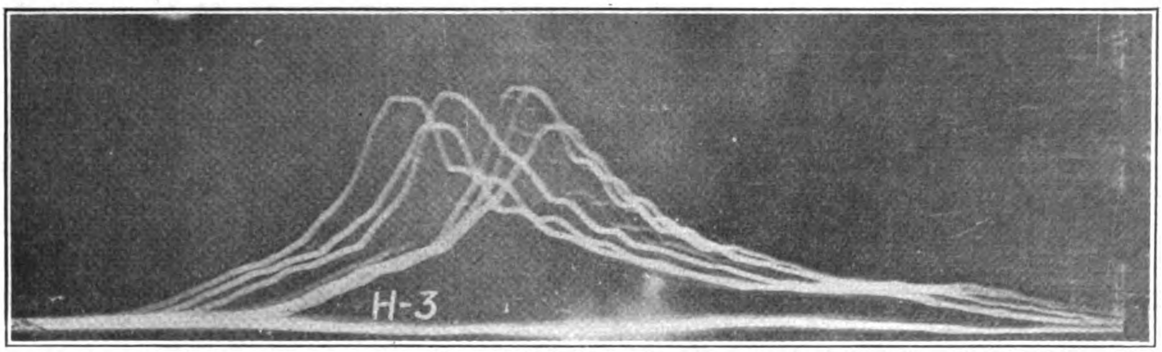


FIG. 16.—H-3.—Aviation gasoline with 5 per cent General Motors Anti-Knock No. 1. B. M. E. P. 127.3 pounds per square inch. Throttled to eliminate detonation.

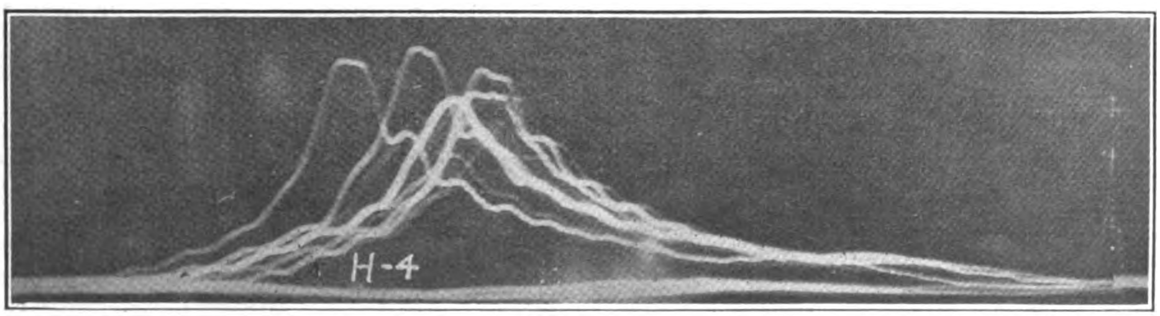


FIG. 17.—H-4.—Aviation gasoline straight. B. M. E. P. 103.6 pounds per square inch. Throttled to eliminate detonation.

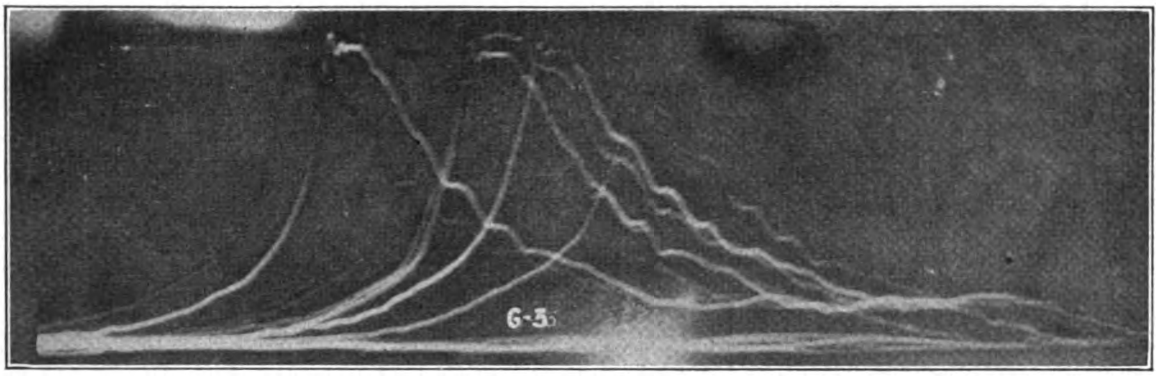


FIG. 18.—G-3.—Low-test gasoline with 18¼ per cent of General Motors Anti-Knock No. 1. B. M. E. P. 144.7 pounds per square inch.

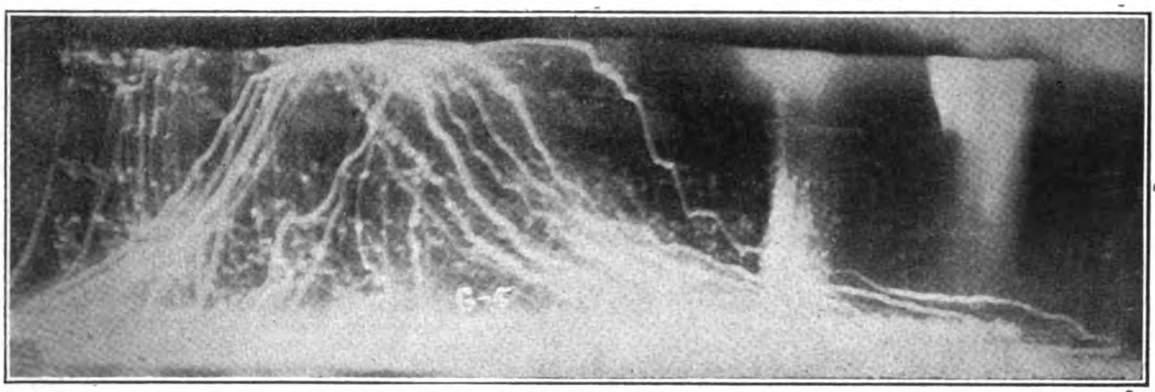


FIG. 19.—G-5.—Preignition. Aviation gasoline.

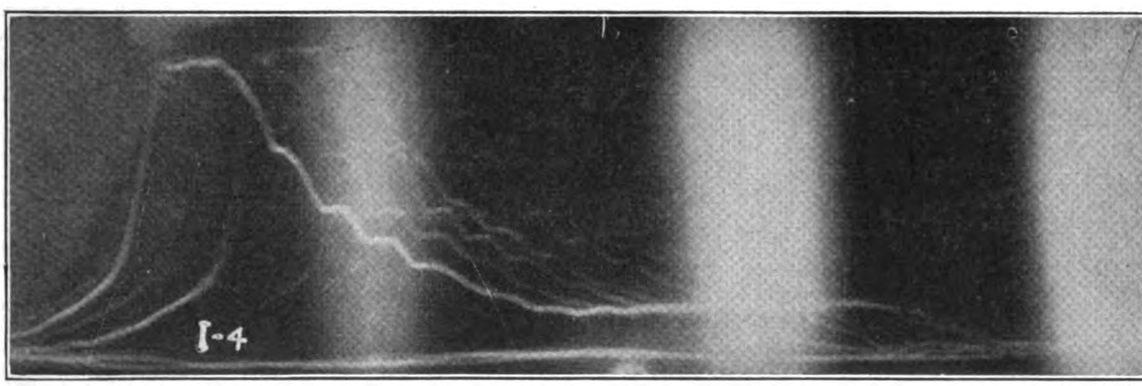


FIG. 20.—I-4.—Benzol. Two spark plugs, one under exhaust valve and one in top of head. B. M. E. P. 146 pounds per square inch. Spark advance 36°.

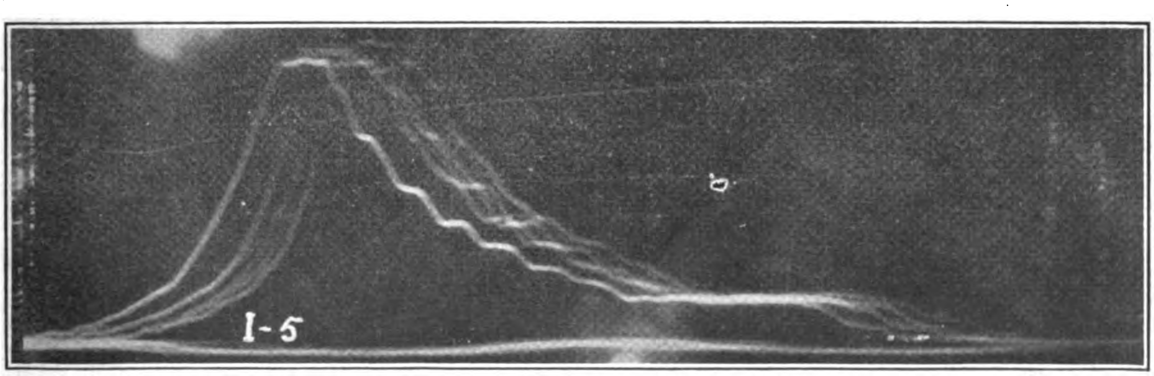


FIG. 21.—I-5.—Benzol. One spark plug only, under exhaust valve. B. M. E. P. 146 pounds per square inch. Spark advance 40°.

McCOOK FIELD REPORT, SERIAL No. 1753

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV March 15, 1922 No. 320

DETERMINATION OF WATER IN GASOLINE AS RECEIVED—EXPOSED TO ATMOSPHERE, TO HUMID ATMOSPHERE, AND SATURATED WITH WATER

(MATERIAL SECTION REPORT No. 156)

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
October 20, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

DETERMINATION OF WATER IN GASOLINE AS RECEIVED—EXPOSED TO ATMOSPHERE, TO HUMID ATMOSPHERE, AND SATURATED WITH WATER.

GENERAL.

Considerable trouble has been experienced due to an inorganic salt deposit that forms in the carburetor. This sediment or corrosion seems to be worse when the engine is allowed to remain idle for a time after use than when in continual use.

An incomplete analysis of this sediment showed it to contain largely aluminum oxide, which contained a considerable amount of moisture. Various reports mention that this is of a slimy consistency at first, but later becomes a gray-white amorphous powder.

From these analyses and reports it was thought, under conditions of exposure to atmosphere, to humid atmosphere, etc., that sufficient water would be collected in the gasoline to cause the formation of aluminum hydroxide by the hydrolytic action of the weak acid carbonic or oxyacide.

PURPOSE.

The purpose of this investigation was to ascertain whether, under various conditions of humidity, appreciable amounts of water were absorbed by gasoline to cause this corrosion, and to investigate several methods for determining water in gasoline.

CONCLUSIONS.

The method described herein for determining small amounts of water in gasoline gave satisfactory results. The results obtained by this method showed that aviation gasoline, as received, contains only a very small per cent of H_2O— 0.006 per cent by weight; that exposure to the atmospheric conditions of humidity did not affect the per cent of water in gasoline appreciably; that exposure to atmosphere of 96 per cent humidity showed hardly any increase in the amount of water dissolved. Gasoline, saturated with H_2O at 75° F., gave H_2O to the extent of 0.009 per cent by weight.

This very small amount of water, as found in gasoline, would hardly account for the corrosion and sediment found in the carburetors.

50 c. c. sample gasoline, sp. gr. 0.7000.	Increase weight, both bulbs.	Blank.	Per cent H^2O, by weight.
	Grams.	*Grams.*	*Per cent.*
As received	0.0041 .0040 .0042	0.0028	0.004
Exposed to the air 2 weeks	.0046	.0028	.005
Exposed to humid air	.0046	.0028	.005
Saturated with H^2O at 75° F.	.0052	.0028	.007

In order to determine whether this method gave quantitative results, a drop of the H^2O was added to a Na dried sample and the regular procedure followed. Excellent results were obtained.

	Gram.
Added water	0.0111
Increased weight of bulbs	.0128 − Blank of 0.0028 = 0.0106
Increased weight of H^2O found	.0106

DISCUSSION OF RESULTS.

An attempt to determine per cent of water in gasoline was made by means of measuring evolved hydrogen upon the addition of sodium to the sample. Satisfactory results were not obtainable, due to the very high vapor pressure of the gasoline.

The method finally employed is the one outlined by C. W. Clifford in the July, 1921, issue of the Journal of Industrial and Engineering Chemistry. Some changes were made in the apparatus, but the principle is the same.

The drying of the samples for blank and method of checking determination was accomplished by adding small pieces of metallic Na. This was then allowed to stand for two hours with occasional shaking.

The samples exposed to the air for two weeks were placed in a small-mouthed bottle and left open. Those exposed to humid atmosphere were placed in a similar container inside a humidity chamber, where an approximate humidity of 96 per cent was maintained for 48 hours.

The sample, saturated with water, was maintained at 75° F. for one hour, or until a complete separation of the excess water was accomplished.

MATERIALS.

Examinations for water content were made on samples of gasoline taken from the small truck used for filling airplane-gasoline tanks. Tests showed these samples to be of uniform quality and to comply with War Department Specification 2-40 for "Aviation gasoline."

APPARATUS.

The apparatus used in the determination consisted of two $CaCl_2$ towers for drying the air before passing it through the sample. A Meyer bulb tube contained the sample and two $CaCl_2$ U tubes filled with 20-mesh $CaCl_2$.

PROCEDURE.

A distillation curve (see fig. 1) was plotted on the sample of gasoline tested in this determination.

A 50 c. c. portion of this sample after drying with Na was placed in the Meyer tube. The two $CaCl_2$ tubes, through which dry air had been passed for 15 minutes, were weighed and connected to the Meyer tube. The dried air was passed through the sample for two hours at a rate of approximately 7 liters per hour. This gave a slight increase in weight on the bulbs, which was used as the blank on all later determinations.

In order to determine the adaptability of the method, a drop of water, of known weight, was then placed in another 50 c. c. of dried sample and run the same way as the blank.

Samples of gasoline as received, exposed to the atmosphere for two weeks, exposed to humid atmosphere for 48 hours, and saturated with water at 75° F., were next run for water content.

Care was taken not to admit moisture into the apparatus while changing the samples.

RESULTS.

The blank, as determined on a number of analyses, gave consistent results of 0.002 gram increase in weight on the bulbs.

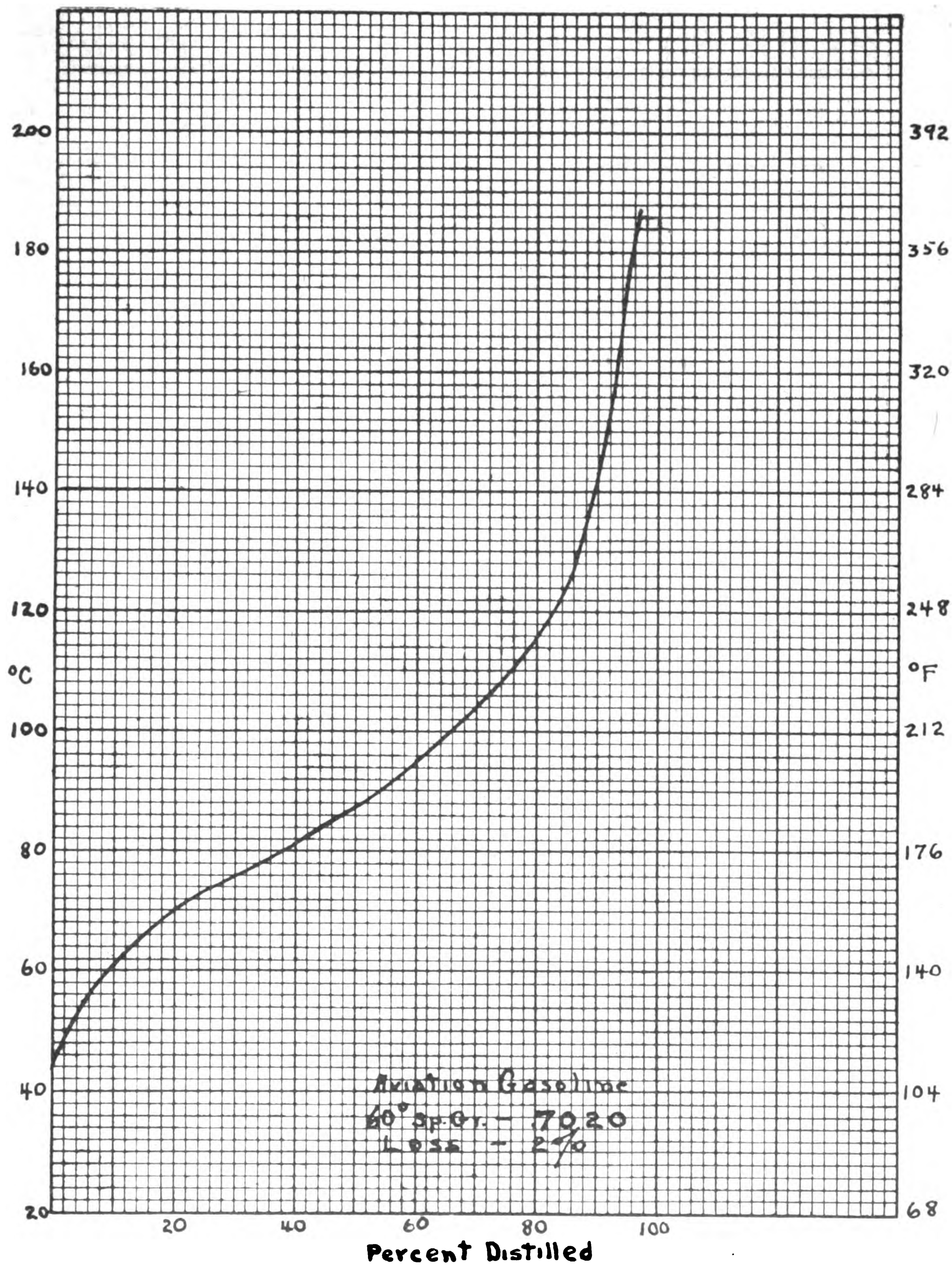

200
180
160
140
120
°C
100
80
60
40
20
392
356
320
284
248
°F
212
176
140
104
68
Aviation Gasoline
60° Sp. Gr. — .7020
Loss — 2%
20
40
60
80
100
Percent Distilled

Fig. 1.

[redacted]

File D 52.1/373 *McCOOK FIELD REPORT, SERIAL No. 1756*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 321

REPORT OF WIND TUNNEL TEST OF CORPS OBSERVATION CO-1 MODEL

(AIRPLANE SECTION, S. & A. BRANCH)

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
October 3, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT OF WIND TUNNEL TEST OF CORPS OBSERVATION CO-1 MODEL.

A 1/36 scale model of the corps observation CO-1 airplane, designed by the Engineering Division, Air Srevice, was tested in the routine manner, lift, drag and moments being determined for a range of stabilizer settings of from $+2°$ to $-6°$ to the thrust line. The model had various changes made on it from time to time. These changes were made to get the proper downwash on the tail surfaces for longitudinal stability.

RESULTS.

With the model as modified the second time—that is, with the upper surface of the wing at the center section continuous and the cut-out at the bottom of the wing—the airplane will balance at 3° incidence with a tail setting of $-2°$.

DISCUSSION.

The model, as first submitted, had the center section cut away for 86 inches on the full scale airplane, which did away with the downwash influence of the wings on the tail. Since the span of the tail plane is 114 inches, only 28 inches of the tail is influenced by wing downwash. The airplane, in this case, would balance at $+2°$ with a stabilizer setting of $-8°$ to the thrust line, but would not be sufficiently maneuverable. In order to verify the downwash hypothesis, the center section of the wing was filled in with plasticene, the superstructure pilot's cabin and gunner's wing cut-out were carefully faired, and the gunner's cockpit was left undisturbed.

A test of the machine with the wing thus modified, with stabilizer settings of 0° and $-2°$, substantiates the downwash explanation. With a stabilizer setting of $-2°$, the machine would then balance at approximately $3\frac{1}{2}°$, and further shows a marked improvement as far as maneuverability is concerned. An additional test was made with a stabilizer setting of 0°, with the wing filled in as before, but the gunner's wing cutaway left open. The results of the test were practically identical with those of the previous one in which the wing was completely filled in. This would indicate that the portion of the wing which was cut away for the gunner's vision did not appreciably affect the wing downwash, but the superstructure in conjunction with that portion of the wing cut away for the pilot's cabin and for increased vision were the dominating factors in affecting the downwash.

If the center of gravity is moved back 0.175 inch on the model or 6.3 inches on the full scale airplane, and the stabilizer set at $-6°$ to the thrust line, the airplane will balance at approximately 4° and be highly maneuverable.

Since these changes were out of the question, the model was changed so that the wing had the cutaway on the lower surface instead of the upper. In this way the wing had a continuous upper wing contour, which would cause a downwash from the wings on to the tail surfaces.

The model was supported on its wing tip and tested with stabilizer settings of 0°, $-2°$, and $-4°$ to the thrust line. The model will possess statical longitudinal stability at all angles of attack with a tail plane setting of $-4°$ to the thrust line and balance at 4° incidence if the center of gravity is shifted back 0.12 inch on the model or 4.3 inches on the full-size airplane. When allowance is made for full flight conditions, the airplane will balance at 3° if the center of gravity is shifted in accordance with the above recommendation.

In June another series of tests was run to determine the correct stabilizer setting for correct balance of the airplane. The downwash of the wings and body was determined by using the tail plane as an exploring plane. Four cases of downwash due to the wings and body were tested. One test of the downwash due to wings alone was made.

The five cases for the wings and body were:

Body in position:

1. Model as submitted.
2. Upper wing camber and gunner's cockpit faired.
3. Upper and lower wing camber and gunner's cockpit faired.
4. Lower wing camber faired, upper camber and gunner's cockpit unfaired.
5. Wing alone faired as for wing and body.

With reference to the curve (fig. 13), it is seen that the downwash angle of the original model (1) is increased over the entire range by filling in the upper camber at the center section; (2) the absence of an upper camber is responsible for the large negative tail setting required to balance this machine. It was shown by a previous test that for proper balance the tail setting should be $-4°$ to the thrust line. A comparison of curves (1) and (2) show that if the center section had not been altered, i. e. if the contour of the upper camber had been preserved, the tail setting required for balance would have been 2° less or approximately $-2°$ to the thrust line.

The downwash angle for the original model (1) is decreased but slightly by fairing in of the lower camber (4).

As was to be expected, alteration of the lower wing surface had less effect on the downwash than modification of the upper surface.

When both the upper and lower camber are faired at the center section (3) the downwash angle is decreased below the angle of maximum lift and increased above when compared with (2).

Cases (3) and (5) are identical except for the removal of the body and indicate that downwash is not influenced appreciably by the body except at and beyond the angle of maximum lift for the model.

The change in downwash due to alteration of the wing form at the center section of a machine is of importance. It would seem that no quantitative prediction can be made of the result of such changes on the downwash

angle. It is desirable, whenever possible, to maintain the full wing section for that portion of the span of a machine which influences the downwash. If visibility is to be obtained by a modification of wing contour, the lower wing surface should be altered to obtain the desired effect. When radical departures in the wing contour are made, as in the case of the CO-1, for reasons of visibility or balance, ordinary empirical methods for the prediction of downwash are of little avail.

The L/D of 7.99 is quite high for a model mounted on an end spindle.

The results are given in the following tables and curves.

Figure 14 shows the original CO-1 model and figure 15 shows the modified CO-1 with the cut-out transferred from the top to the bottom of the wing.

TABLE 1.—*Original model, stabilizer 0° to T. L.*

CASE A.

Θ	L.	D.	L/D.	X.	Z.	M.
−4	−0.164	0.0565	−2.90	0.0449	−0.167	−0.107
−2	− .013	.0500	− .26	......	......	......
0	+ .144	.0490	+2.94	.0490	+ .144	− .189
2	.305	.0539	5.66	......	......	......
4	.442	.0613	7.21	+ .0303	.445	− .259
6	.579	.0734	7.89	......	......	......
8	.696	.0863	8.07	− .0112	.701	− .330
10	.808	.1055	7.66	......	......	......
12	.896	.1301	6.88	− .0593	.903	− .440
14	.920	.1684	5.46	− .0590	.933	− .525
16	.901	.2198	4.09	− .0367	.926	− .613

TABLE 2.—*Original model, wings filled.*

CASE B.

Θ	L.	D.	L/D.	X.	Z.	M c. g.	
						Stab. 0°.	Stab. −2°.
0	0.210	0.0402	5.23	0.040	0.210	−0.083	+0.037
4	.527	.0536	9.83	+ .016	.529	− .130	− .008
8	.822	.0793	10.36	− .035	.824	− .190	− .070
12	1.101	.1186	9.29	− .113	1.103	− .276	− .155
14	1.179	.1395	8.45	− .151	1.177	......	......
16	1.223	.1695	7.22	− .175	1.222	− .400	− .284
18	1.090	.2700	4.04	− .081	1.120	......	......

Θ= Angle $\begin{Bmatrix}\text{incidence}\\ \text{pitch}\end{Bmatrix}$ (with relation to T. L.).
L= Lift on model (pounds).
D= Drag on model (pounds).
X= Longitudinal force on model (pounds).
Z= Normal force on model (pounds).
M= Moment about c. g. (pounds/inches).
Tested at M. I. T., January and February, 1921. Velocity: 30 m. p. h.
Model $\frac{1}{16}$ scale.

TABLE 3.—*Original model, wings filled and gunner's cut-away open.*

CASE C.

Θ	L.	D.	L/D.	X.	Z.	M.
0	0.180	0.0427	4.22	0.043	0.180	−0.085
4	.483	.0545	8.87	+ .020	.486	− .138
8	.763	.0785	9.72	− .029	.766	− .206
12	1.028	.1139	9.03	− .103	1.026	− .291
14	1.113	.1359	8.20	− .138	1.113	......
16	1.150	.1643	7.00	− .160	1.151	− .400
18	1.032	.2486	4.15	− .073	1.060	......

TABLE 4.—*Wing alone.*

CASE D.

Θ	L.	D.	L/D.	X.	Z.	M.
− 4	−0.128	0.0383	− 3.34	0.029	−0.131	......
0	+ .153	.0319	+ 4.80	.032	+ .153	−0.107
+ 4	.430	.0448	9.60	+ .015	.433	− .071
8	.674	.0668	10.07	− .028	.677	− .050
12	.865	.0987	8.77	− .083	.865	− .043
16	.888	.1723	5.15	− .081	.901	− .130

TABLE 5.—*Original model, moment about c. g. (lbs./ins.).*

CASE A.

[Stabilizer settings other than 0°.]

Θ	Stab. 2°.	Stab. −2°.	Stab. −4°.	Stab. −5.9°.
− 4	−0.184	−0.051	+0.001	+0.055
0	− .271	− .130	− .075	− .019
4	− .331	− .200	− .145	− .078
8	− .410	− .270	− .210	− .156
12	− .520	− .370	− .300	− .248
16	− .713	− .510	− .420	− .360

TABLE 6.—*Original model (special test) Mar. 7, 1921.*

CASE I.

i.	L.	D.	L/D.
4	−0.176	0.0568	−3.10
− 2	− .026	.0485	− .54
0	.120	.0476	+2.52
+ 2	.280	.0515	5.44
4	.420	.0601	7.00
8	.672	.0851	7.90
12	.884	.1306	6.77
16	.889	.2143	4.15

CASE II.

[Triangular blocks removed.]

i.	L.	D.	L/D.
4	−0.167	0.0571	−2.93
− 2	− .028	.0502	− .56
0	.109	.0505	+2.16
+ 2	.265	.0579	4.58
4	.391	.0675	5.79
8	.634	.0937	6.77
12	.852	.1335	6.38
16	.847	.2169	3.91

TABLE 7.—*Modified model, elevators at 0° to tail plane.*

Θ	L.	D.	L/D.	X.	Z.
4	−0.145	0.0594	−2.44	0.048	−0.149
− 2	.002	.0510	+ .09	.051	+ .001
0	.156	.0491	3.18	.049	.156
+ 2	.322	.0531	6.07	.042	.324
4	.460	.0617	7.46	.029	.463
6	.592	.0748	7.92	.013	.595
8	.721	.0903	7.99	− .011	.725
10	.838	.1092	7.67	− .038	.844
12	.961	.1356	7.18	− .069	.968
14	1.055	.1576	6.69	− .103	1.063
16	1.140	.1884	6.05	− .125	1.149
18	1.147	.2315	4.96	− .134	1.162

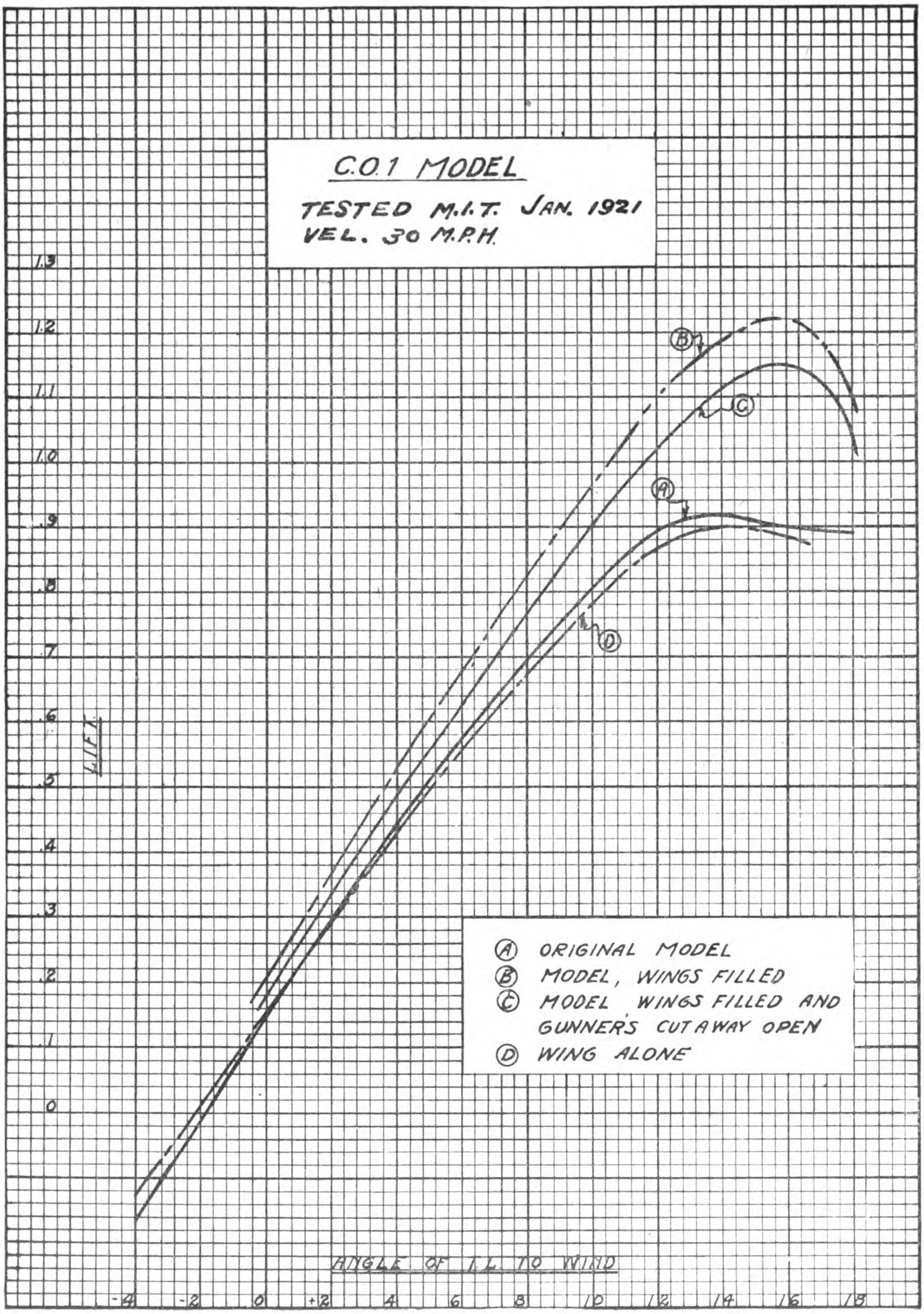
Θ= Angle of thrust line to wing.
L= Lift on model, in pounds.
D= Drag on model, in pounds.
X= Longitudinal force on model, in pounds.
Z= Normal force on model, in pounds.
M= Moment about c. g., in pounds/inches.
Tested at M. I. T., April 15, 1921.
Velocity: 30 m. p. h.
Tail plane settings referred to thrust line.

TABLE 8.—*Modified model (complete, minus tail).*

Θ	L.	D.	L/D.	X.	Z.	M c. g.
−4	−0.095	0.0558	−1.70	0.0491	−0.0985	−0.1859
−2	+ .064	.0492	+1.30	.0513	+ .0622	− .1471
0	.214	.0496	4.11	.0507	.2140	− .1011
+2	.378	.0553	6.84	+.0431	.380	− .0717
4	.505	.0652	7.75	+.0298	.508	− .0389
8	.758	.0944	8.03	−.0121	.765	− .0005
12	.974	.1367	7.12	−.0687	.982	+ .0207
16	1.131	.1884	6.00	−.1320	1.140	+ .0146
20	.887	.3239	2.74	.0000	.945	− .0830

TABLE 9.—*Modified model, M c. g. for tail plane settings.*

Θ	0°	−2°	−4°	−4° c. g. shifted 0.12 inch back.
4	−0.072	−0.029	+0.045	+0.027
−2	− .098	− .058	+ .020	+ .020
0	− .124	− .081	+ .009	+ .018
+2	− .155	− .115	− .029	+ .010
4	− .188	− .132	− .055	+ .000
6	− .219	− .160	− .080	− .009
8	− .254	− .200	− .126	− .039
10	− .306	− .255	− .178	− .067
12	− .345	− .297	− .222	− .106
14	− .395	− .352	− .278	− .150
16	− .446	− .422	− .342	− .204
18	− .561	− .503	− .412	− .273



C.O.1 MODEL
TESTED M.I.T. JAN. 1921
VEL. 30 M.P.H.
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
LIFT
A
B
C
D
Ⓐ ORIGINAL MODEL
Ⓑ MODEL, WINGS FILLED
Ⓒ MODEL WINGS FILLED AND GUNNER'S CUTAWAY OPEN
Ⓓ WING ALONE
ANGLE OF T.L. TO WIND
-4
-2
0
+2
4
6
8
10
12
14
16
18

Fig. 1.

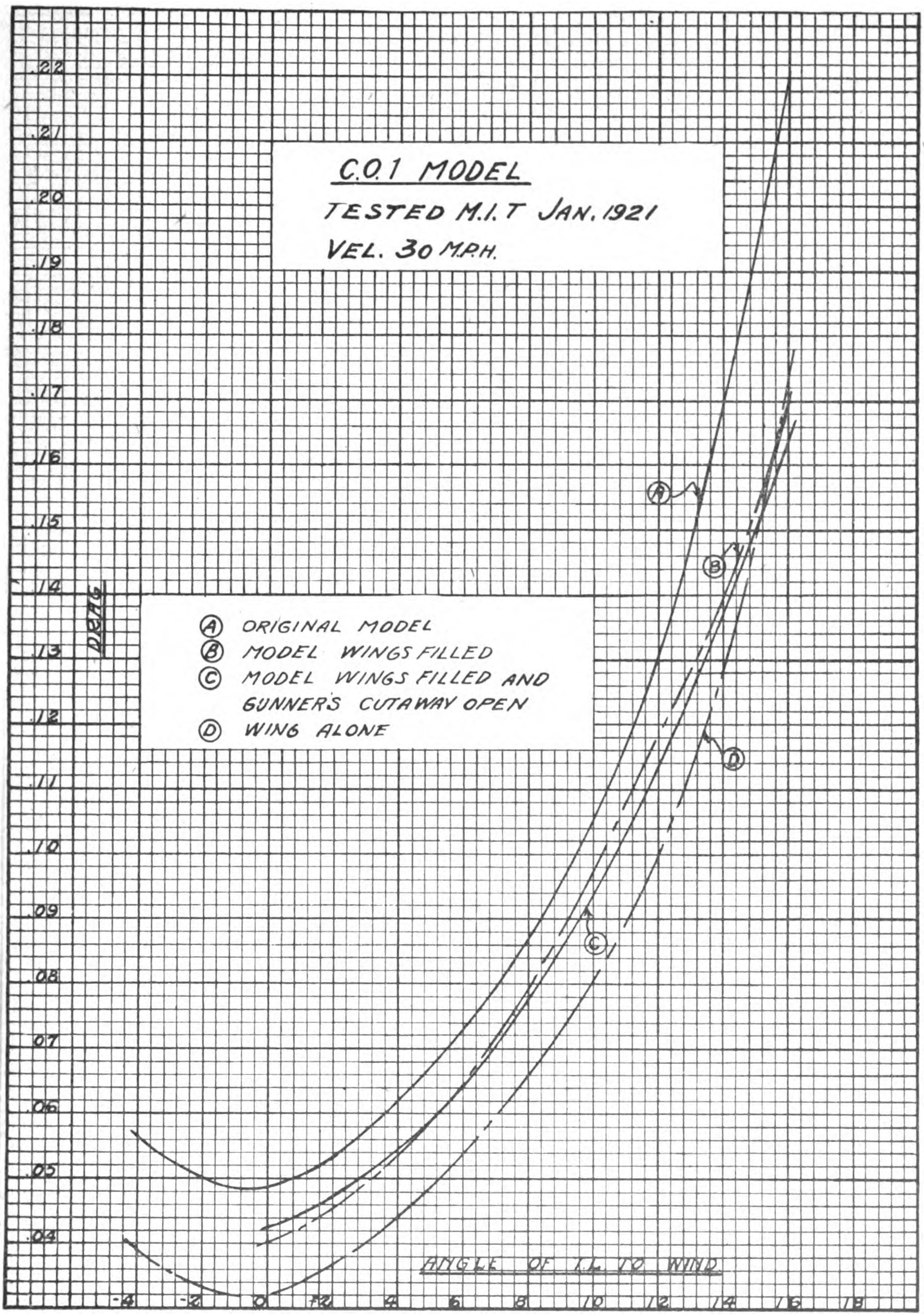

C.O.1 MODEL
TESTED M.I.T JAN. 1921
VEL. 30 M.P.H.
Ⓐ ORIGINAL MODEL
Ⓑ MODEL WINGS FILLED
Ⓒ MODEL WINGS FILLED AND GUNNER'S CUTAWAY OPEN
Ⓓ WING ALONE
DRAG
ANGLE OF I.L. TO WIND
.22
.21
.20
.19
.18
.17
.16
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
-4
-2
0
2
4
6
8
10
12
14
16
18

FIG. 2.

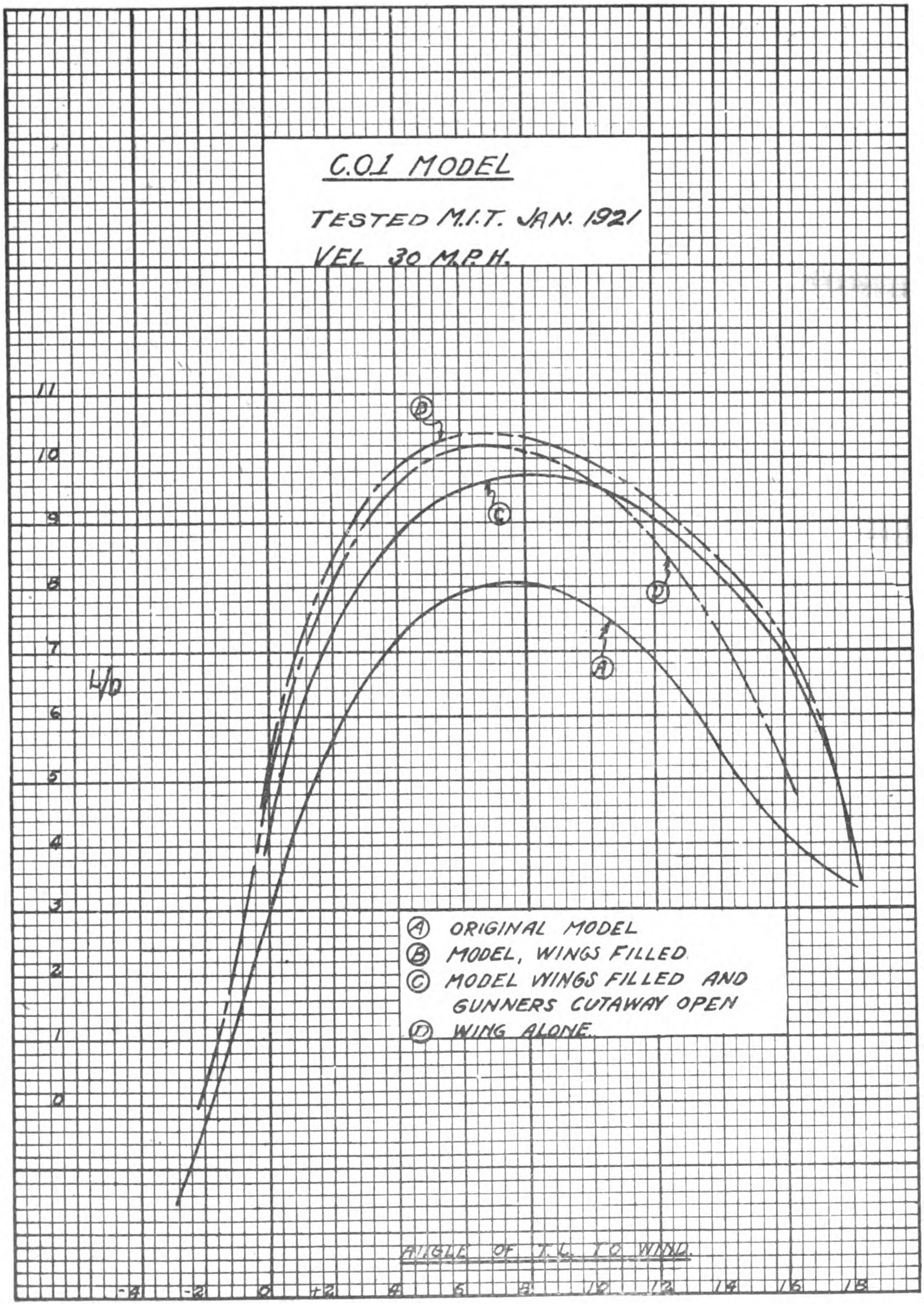
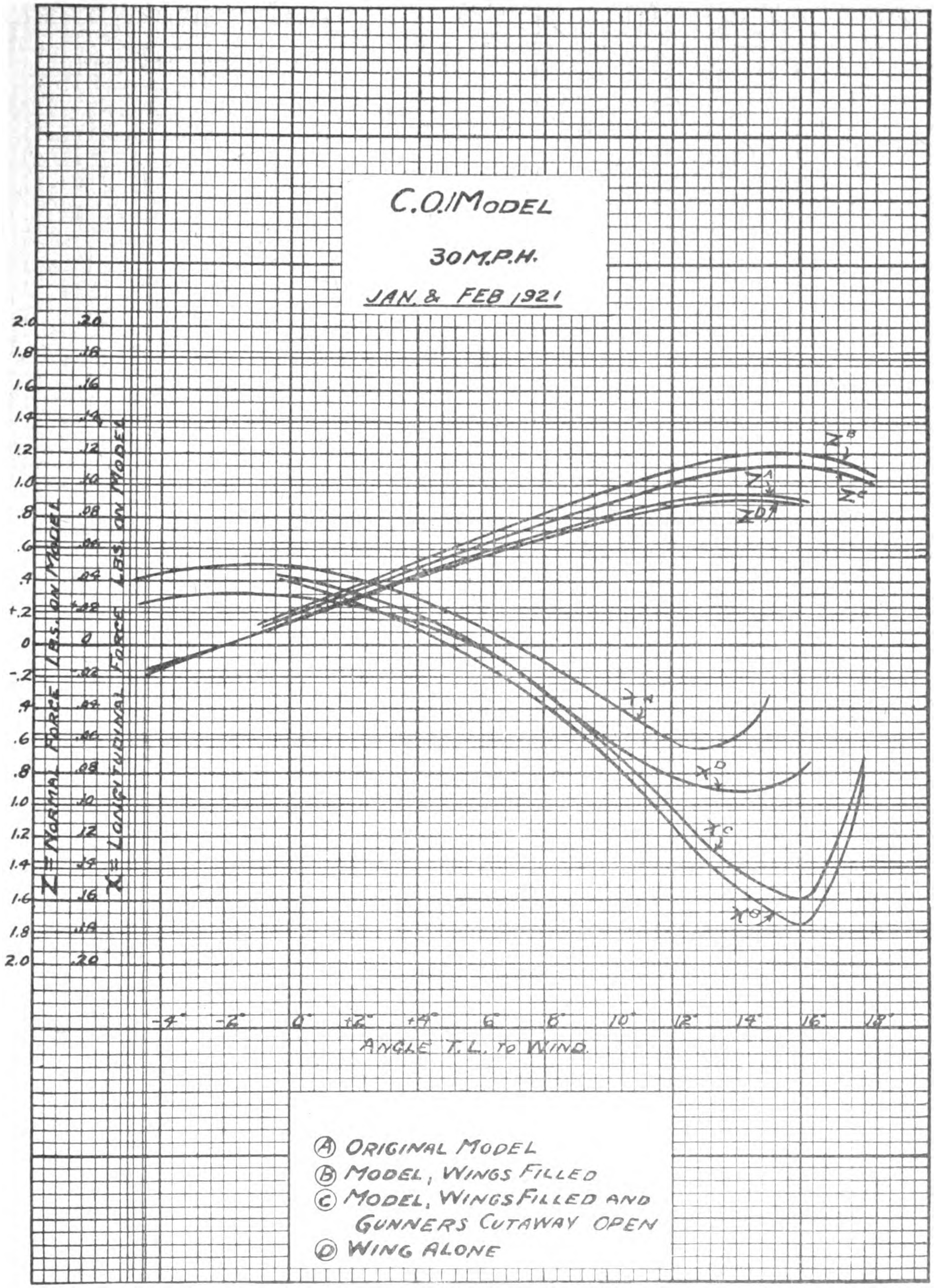
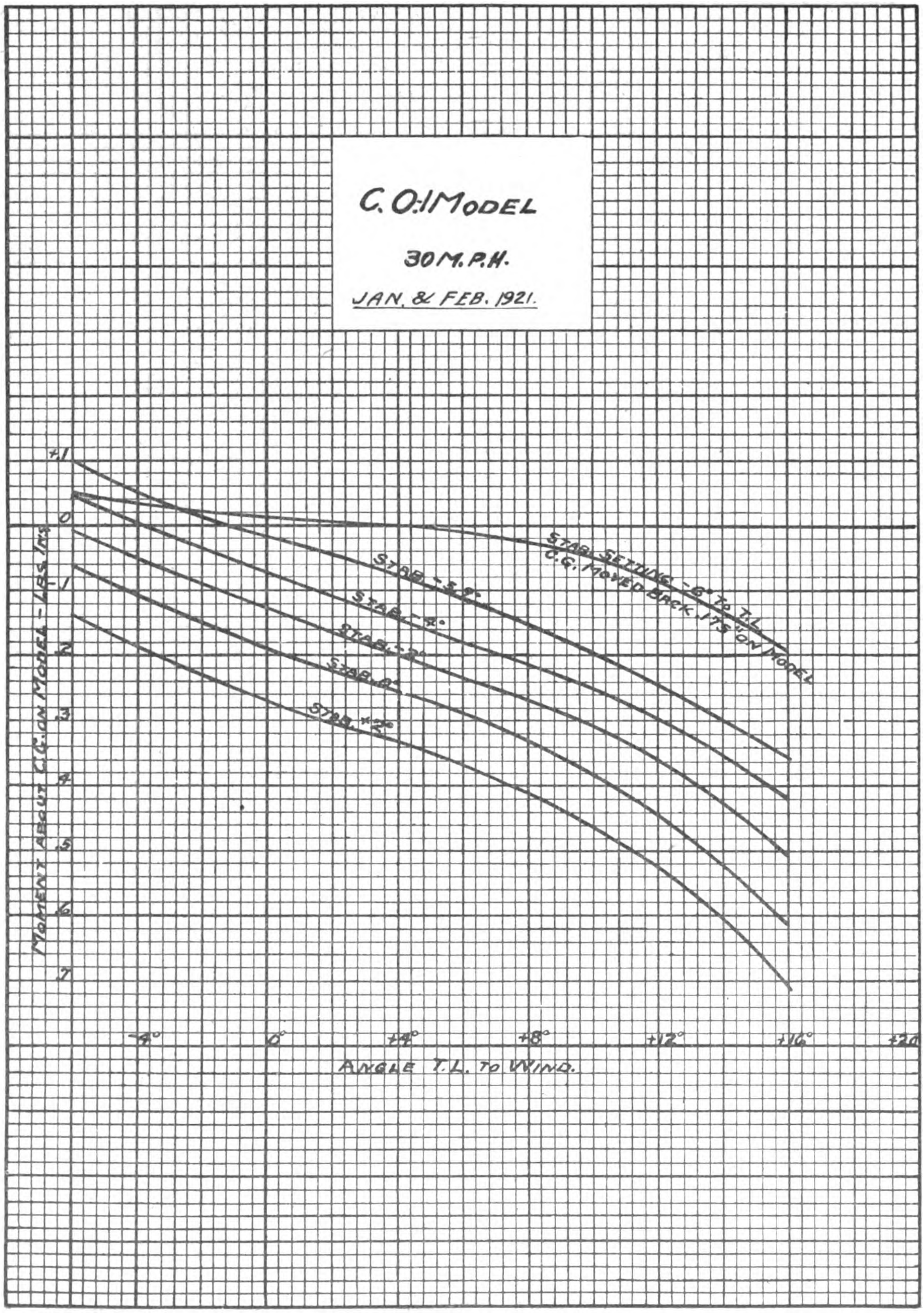

C.O1 MODEL
TESTED M.I.T. JAN. 1921
VEL 30 M.P.H.
L/D
A ORIGINAL MODEL
B MODEL, WINGS FILLED
C MODEL WINGS FILLED AND GUNNERS CUTAWAY OPEN
D WING ALONE
ANGLE OF T.L. TO WIND
-4
-2
0
+2
4
6
8
10
12
14
16
18

Fig. 3.



C.O.1 Model
30 M.P.H.
JAN. & FEB 1921
Z = Normal Force lbs. on Model
X = Longitudinal Force lbs. on Model
Angle T.L. to Wind.
(A) Original Model
(B) Model, Wings Filled
(C) Model, Wings Filled and Gunners Cutaway Open
(D) Wing Alone

Fig. 4.



C. O:1 MODEL
30 M.P.H.
JAN. & FEB. 1921.
STAB. SETTING -6° TO T.L.
C.G. MOVED BACK 1⅞" ON MODEL
STAB. -5.2°
STAB. -4°
STAB. -2°
STAB. 0°
STAB. +2°
MOMENT ABOUT C.G. ON MODEL - LBS. INS.
ANGLE T.L. TO WIND.
-4°
0°
+4°
+8°
+12°
+16°
+20

FIG. 5.

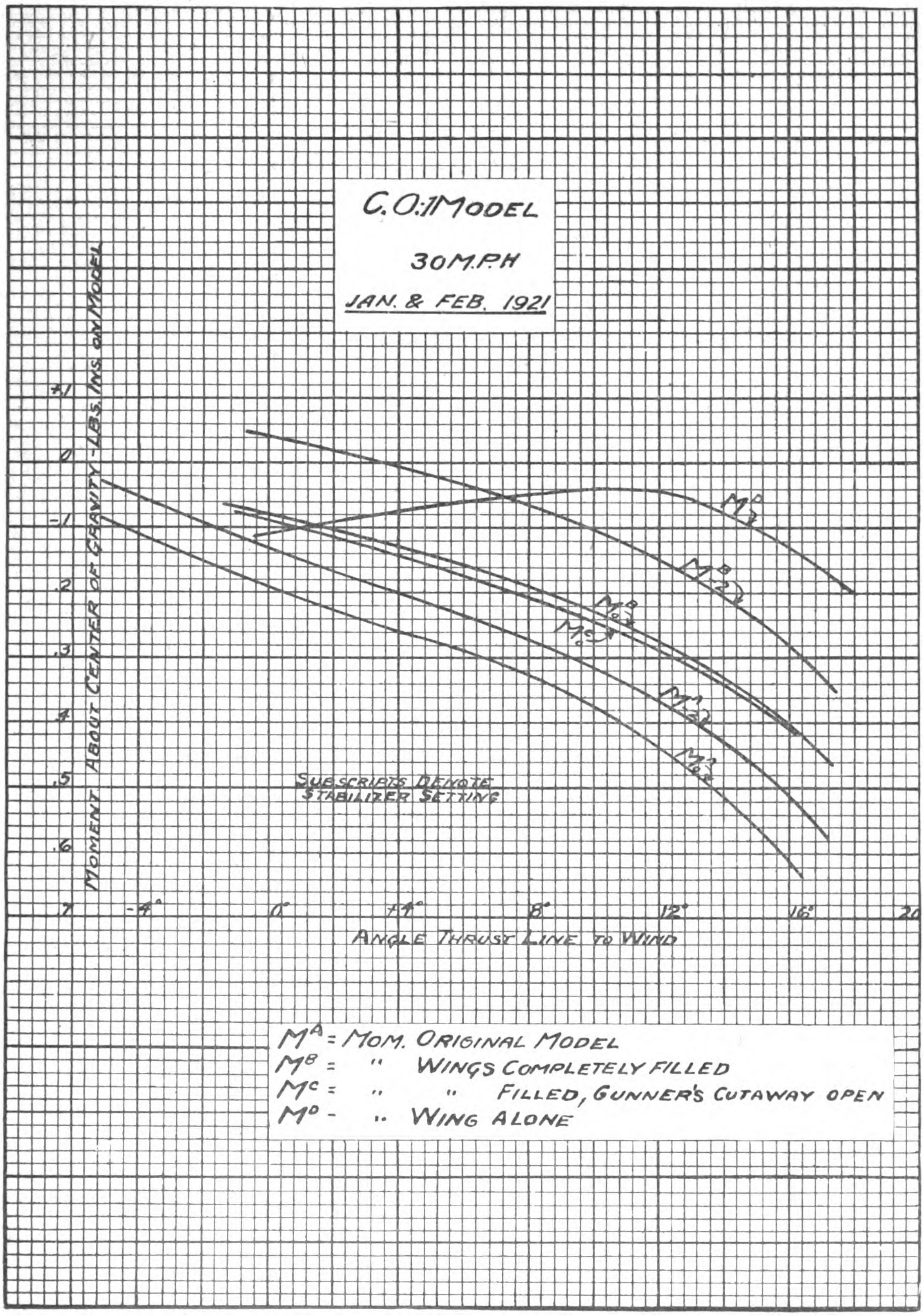

C. O. 1 MODEL
30 M.P.H
JAN. & FEB. 1921
MOMENT ABOUT CENTER OF GRAVITY - LBS. INS. ON MODEL
+1
0
-1
.2
.3
.4
.5
.6
.7
-4°
0°
+4°
8°
12°
16°
20
ANGLE THRUST LINE TO WIND
SUBSCRIPTS DENOTE STABILIZER SETTING
M^A = MOM. ORIGINAL MODEL
M^B = " WINGS COMPLETELY FILLED
M^C = " " FILLED, GUNNER'S CUTAWAY OPEN
M^D - " WING ALONE

FIG. 6.

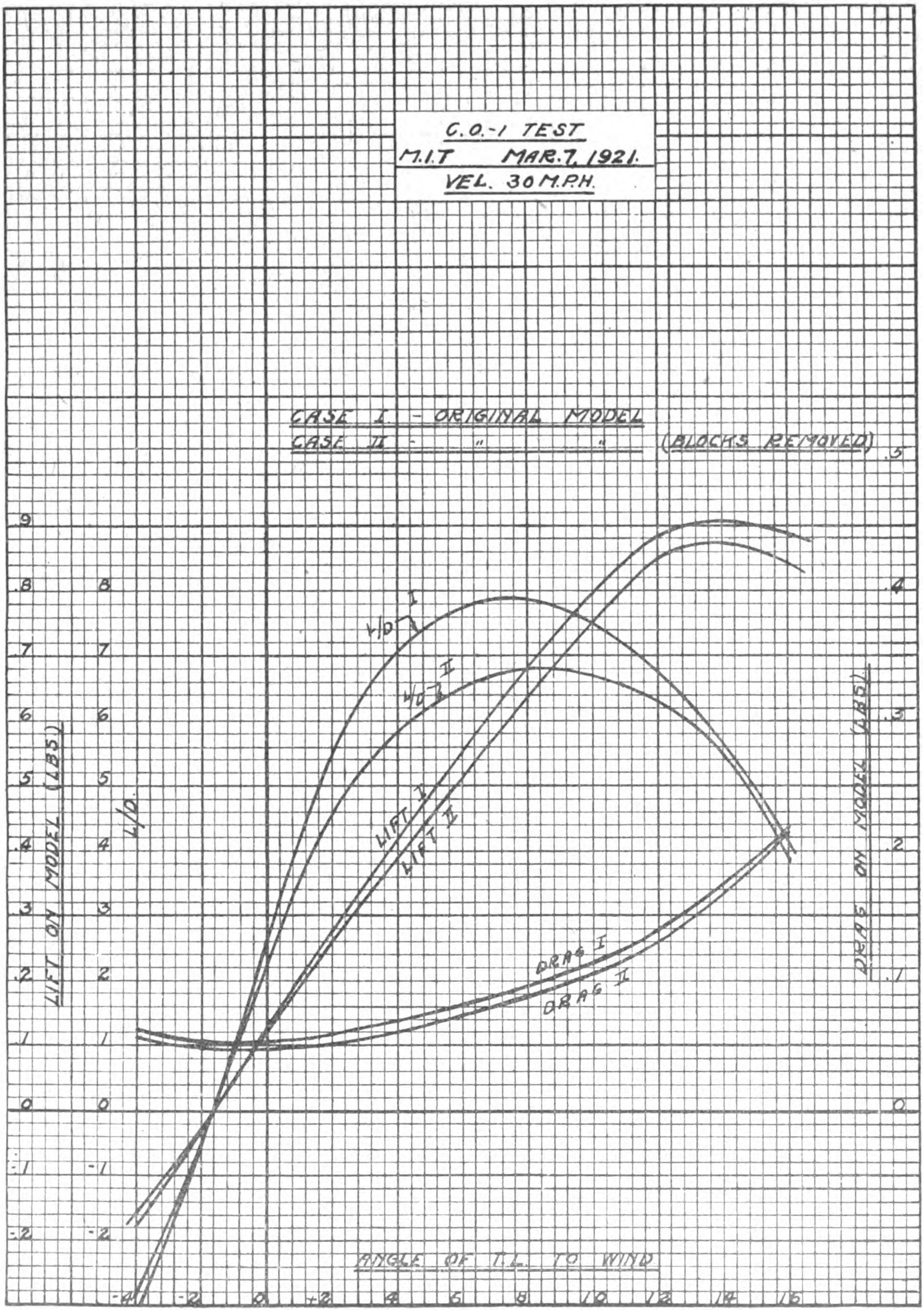

C.O.-1 TEST
M.I.T MAR.7, 1921.
VEL. 30 M.P.H.
CASE I - ORIGINAL MODEL
CASE II - " " (BLOCKS REMOVED)
L/D I
L/D II
LIFT I
LIFT II
DRAG I
DRAG II
LIFT ON MODEL (LBS)
L/D.
DRAG ON MODEL (LBS)
ANGLE OF T.L. TO WIND
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
8
7
6
5
4
3
2
1
0
-1
-2
.5
.4
.3
.2
.1
0
-4
-2
0
+2
4
6
8
10
12
14
16

FIG. 7.

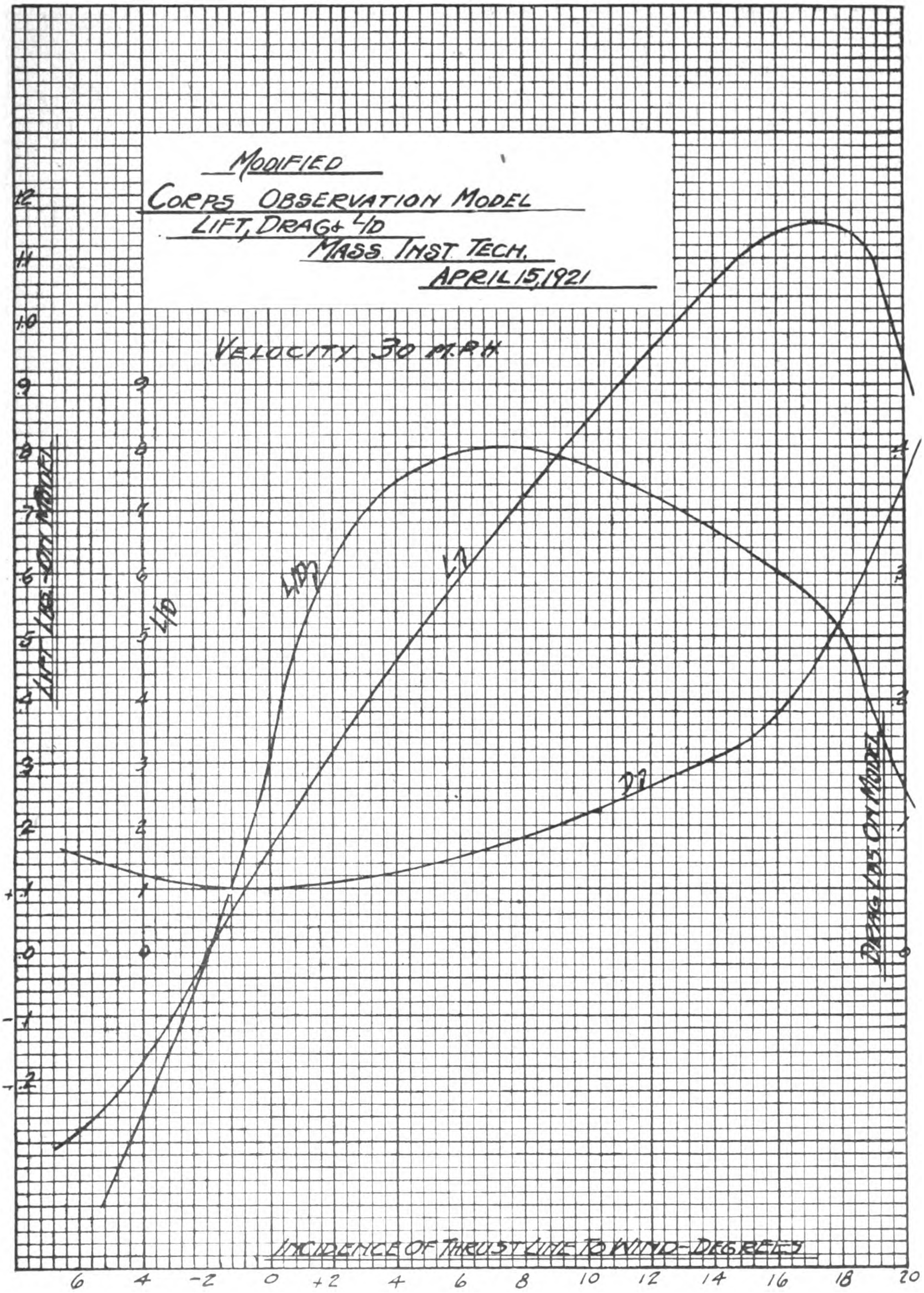

MODIFIED
CORPS OBSERVATION MODEL
LIFT, DRAG & L/D
MASS. INST. TECH.
APRIL 15, 1921
VELOCITY 30 M.P.H.
LIFT LBS. ON MODEL
L/D
DRAG LBS. ON MODEL
INCIDENCE OF THRUST LINE TO WIND–DEGREES

FIG. 8.

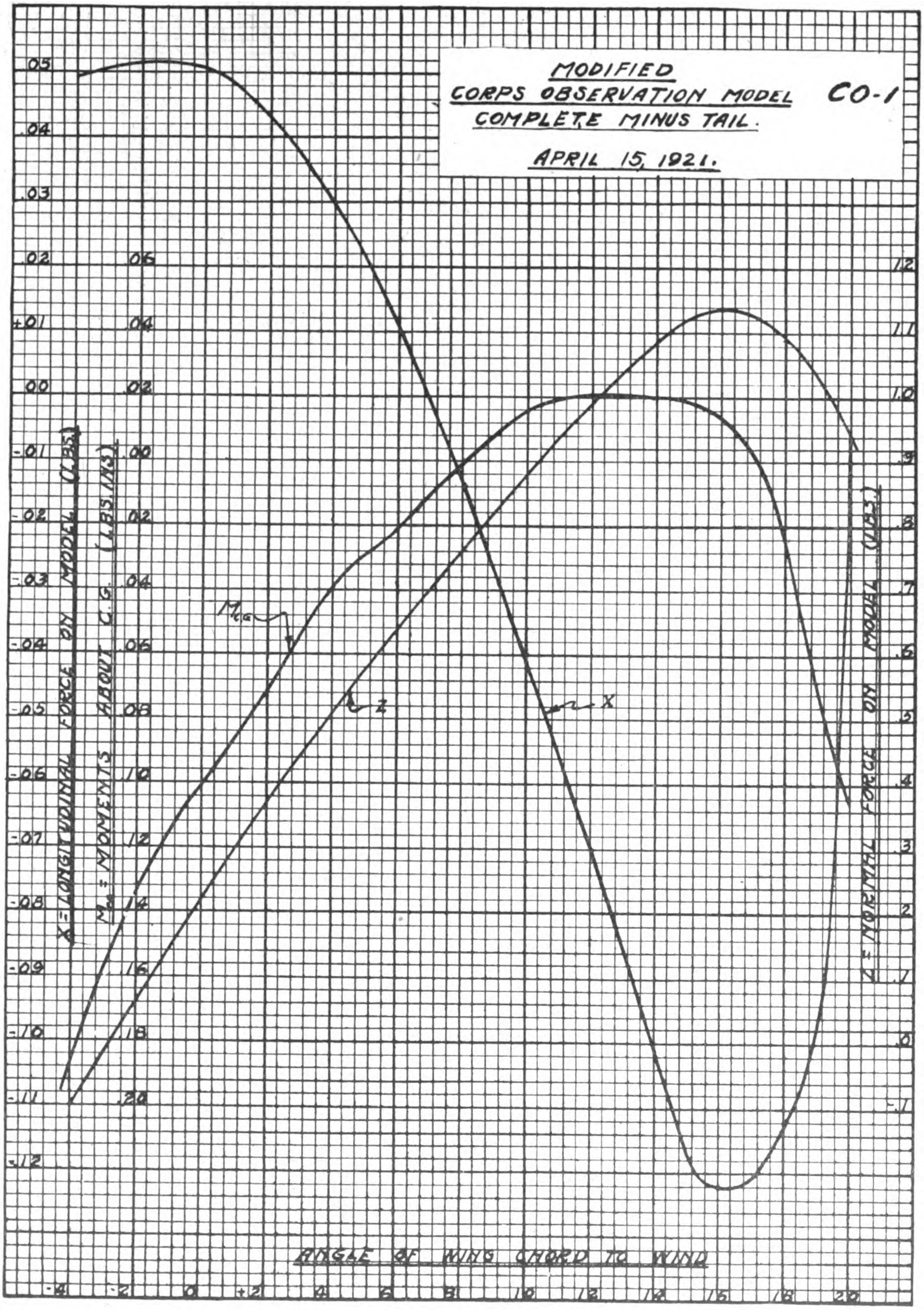
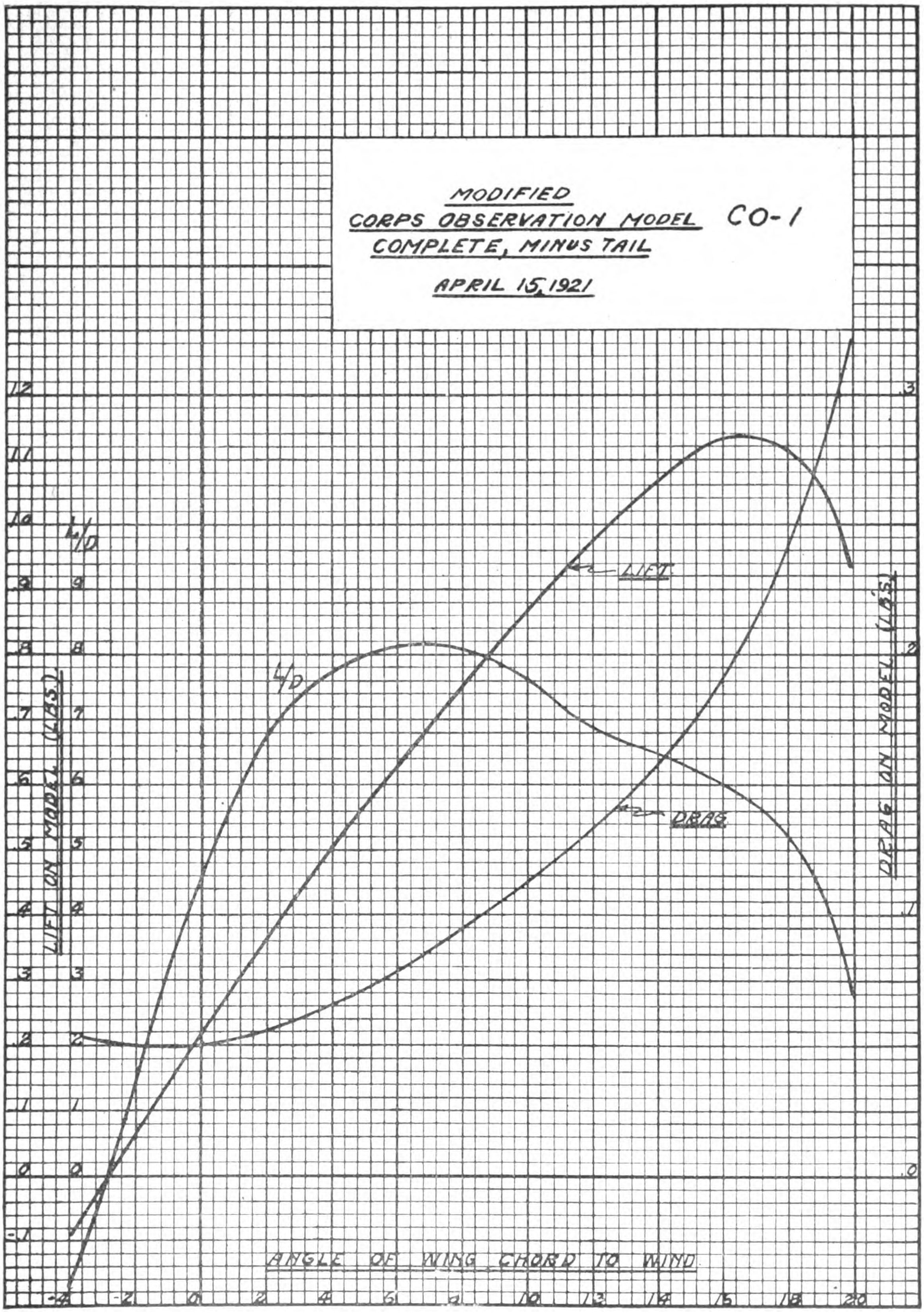

MODIFIED
CORPS OBSERVATION MODEL
COMPLETE MINUS TAIL.
APRIL 15, 1921.
CO-1
X = LONGITUDINAL FORCE ON MODEL (LBS.)
M_{cg} = MOMENTS ABOUT C.G. (LBS. INS.)
Z = NORMAL FORCE ON MODEL (LBS.)
ANGLE OF WING CHORD TO WIND
M_{cg}
Z
X

FIG. 9.



MODIFIED
CORPS OBSERVATION MODEL CO-1
COMPLETE, MINUS TAIL
APRIL 15, 1921
LIFT
DRAG
L/D
LIFT ON MODEL (LBS.)
DRAG ON MODEL (LBS.)
ANGLE OF WING CHORD TO WIND

Fig. 10.

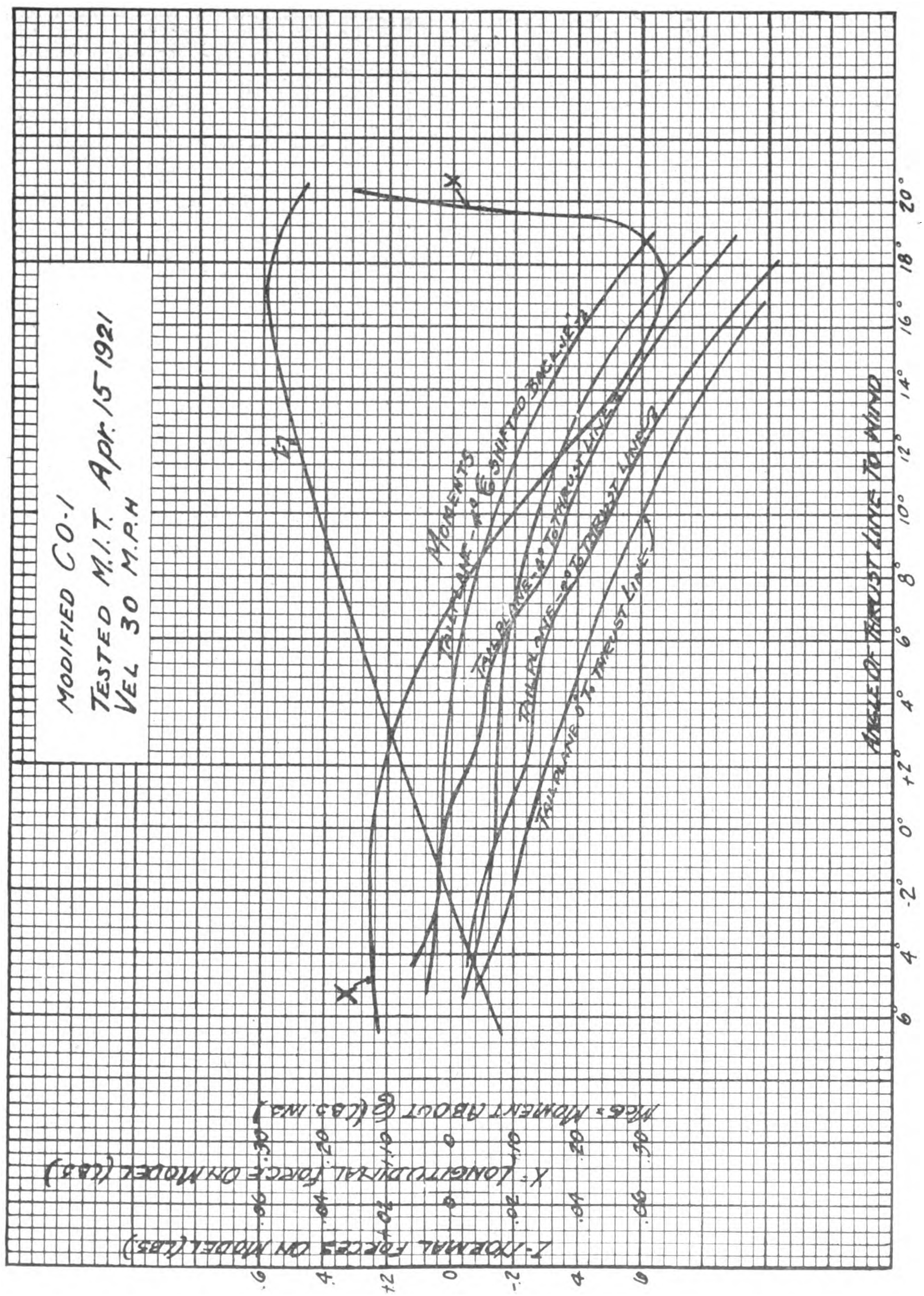
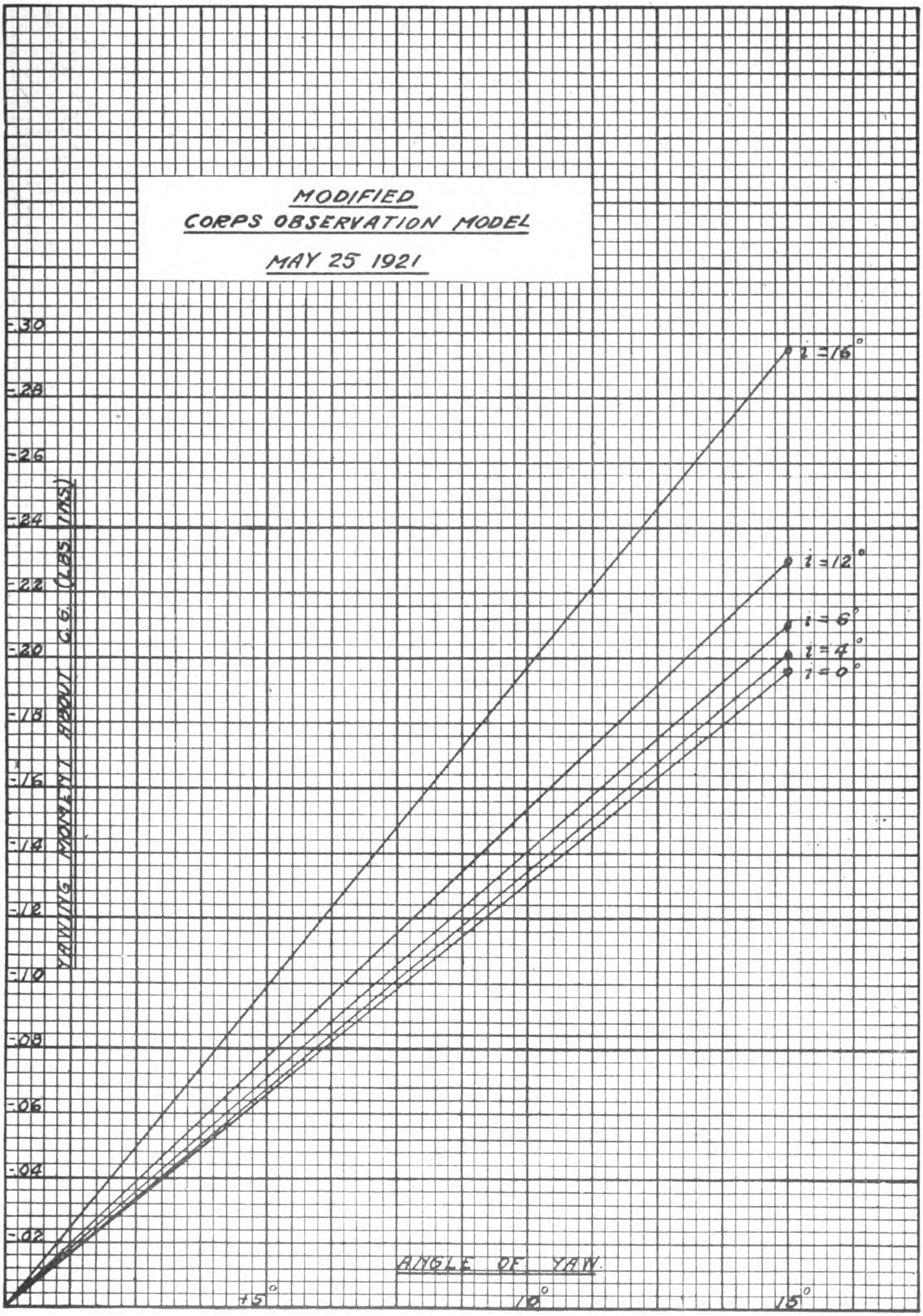

MODIFIED CO-1
TESTED M.I.T. APR. 15 1921
VEL 30 M.P.H
MOMENTS
ANGLE OF THRUST LINE TO WIND
Z - NORMAL FORCES ON MODEL (LBS)
X - LONGITUDINAL FORCE ON MODEL (LBS)
Mcg = MOMENT ABOUT CG (LBS. INS.)

FIG. 11.



MODIFIED
CORPS OBSERVATION MODEL
MAY 25 1921
YAWING MOMENT ABOUT C.G. (LBS. INS.)
.30
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
ANGLE OF YAW
5°
10°
15°
i = 16°
i = 12°
i = 6°
i = 4°
i = 0°

Fig. 12.

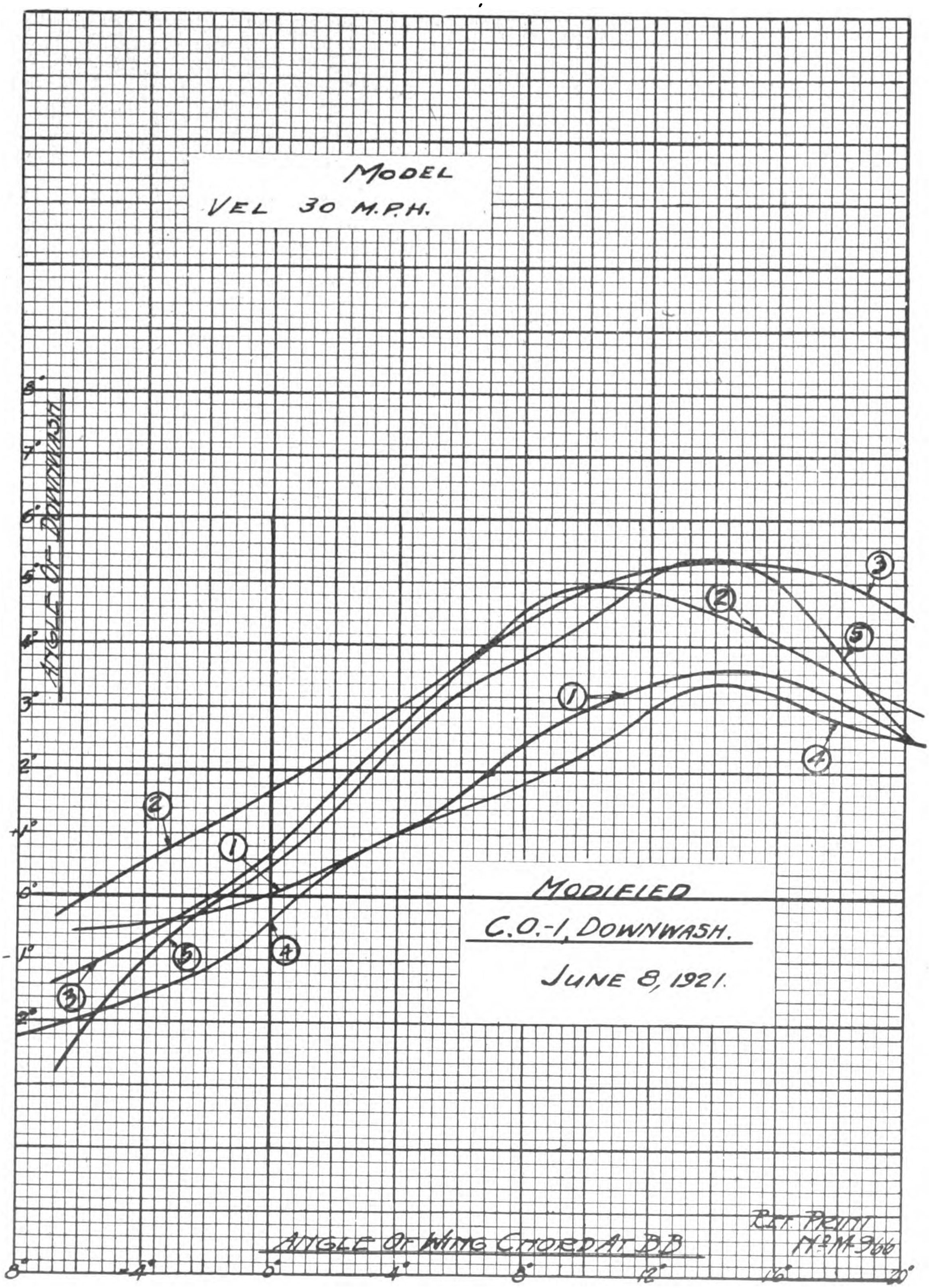

MODEL
VEL 30 M.P.H.
MODIFIED
C.O.-1, DOWNWASH.
JUNE 8, 1921.
ANGLE OF DOWNWASH
ANGLE OF WING CHORD AT B.B
REF. PRINT
N.º M-966

FIG. 13.

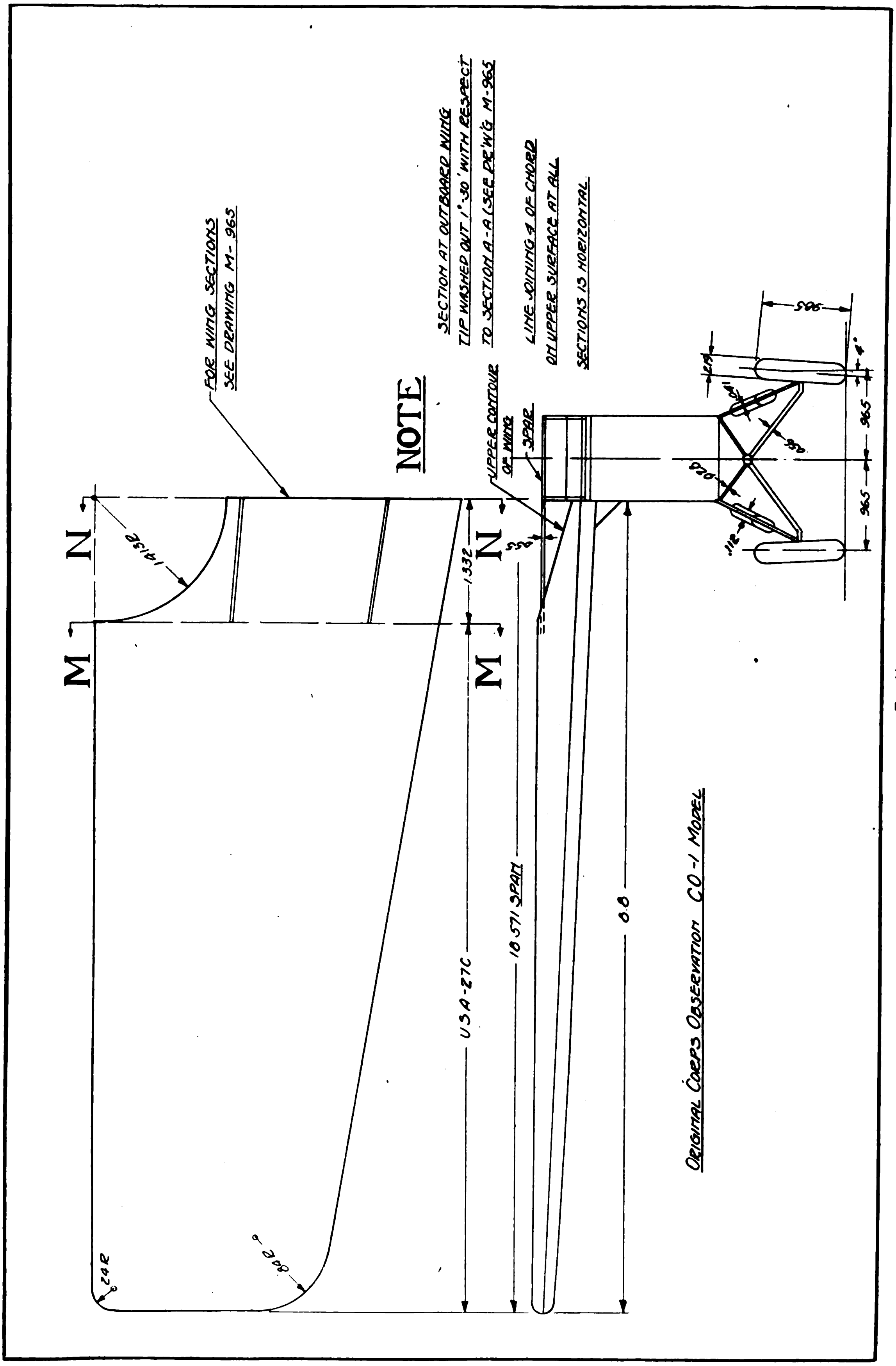
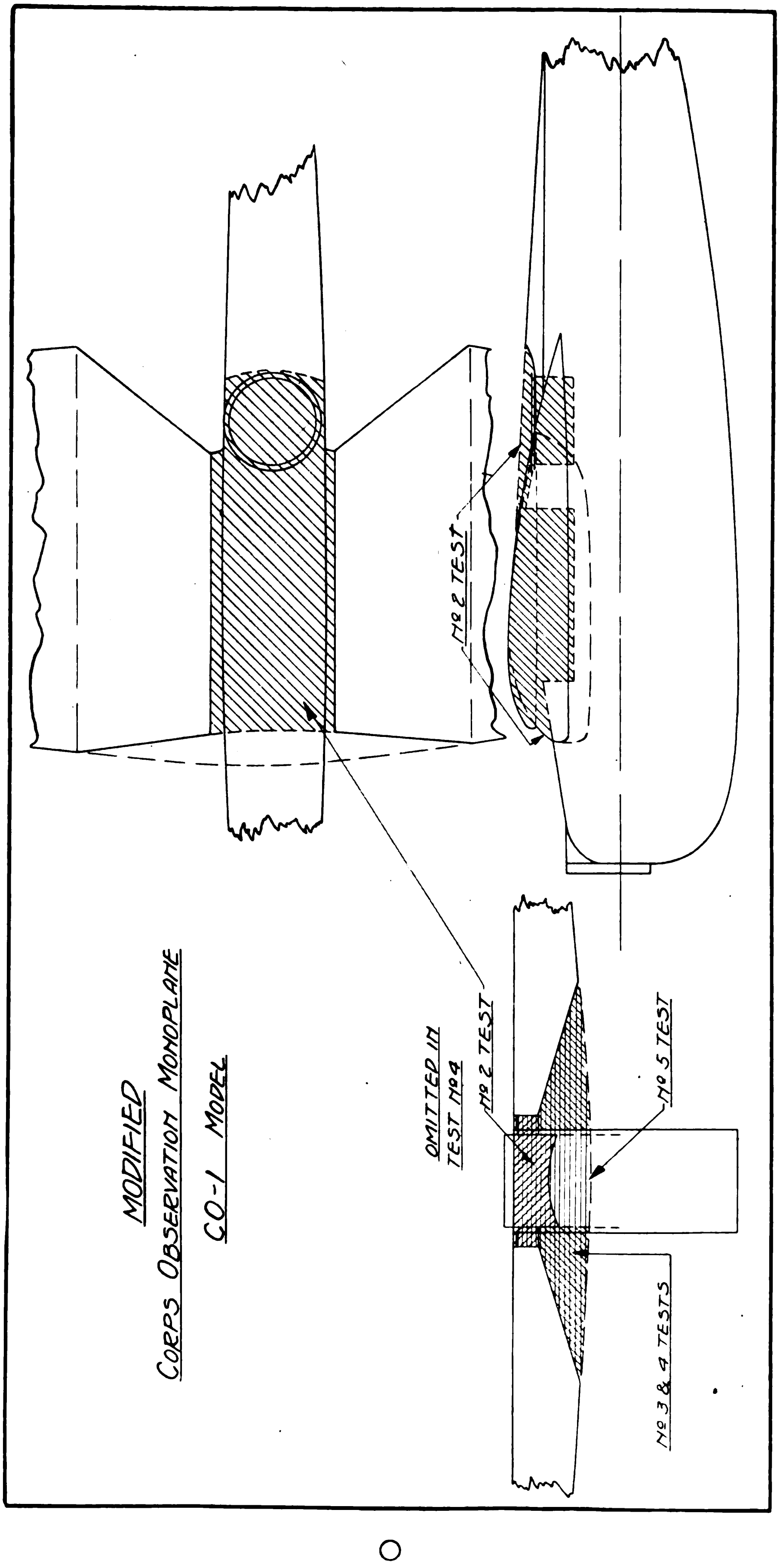

FOR WING SECTIONS SEE DRAWING M-965
NOTE
SECTION AT OUTBOARD WING TIP WASHED OUT 1°-30' WITH RESPECT TO SECTION A-A (SEE DR'W'G M-965
LINE JOINING ¼ OF CHORD ON UPPER SURFACE AT ALL SECTIONS IS HORIZONTAL.
UPPER CONTOUR OF WING
SPAR
N
N
M
M
1.332
USA-27C
10.571 SPAN
8.8
24R
96.5
96.5
965
ORIGINAL CORPS OBSERVATION CO-1 MODEL

Fig. 14.



MODIFIED
CORPS OBSERVATION MONOPLANE
CO-1 MODEL
No 2 TEST
OMITTED IN TEST No 4
No 2 TEST
No 5 TEST
No 3 & 4 TESTS

Fig. 15.

File D 52.1 / S. E. 5 / 46

McCOOK FIELD REPORT, SERIAL No. 1757

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 322

REPORT OF STATIC TEST OF SKI FOR AN SE-5 AIRPLANE

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
October 3, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT OF STATIC TEST OF SKI FOR AN SE-5 AIRPLANE.

OBJECT.

This static test was conducted for the purpose of determining and structural strength of the SE-5 ski.

DATE AND PLACE.

This ski was tested at McCook Field, Dayton, Ohio, February 11, 1921.

WITNESSES.

W. E. Savage. D. B. Weaver.
E. R. Weaver.

SUMMARY.

The ski failed with a load of 12,500 pounds, which is 12 times the load upon it while the airplane is at rest.

The results are satisfactory.

GENERAL DESCRIPTION.

The ski is entirely of wood construction. The top is made of three-ply veneer, mahogany sides and poplar center, and the sides are three-ply veneer with birch outside and poplar center. The runner is of three-ply ash veneer; the over-all thickness is $\frac{3}{8}$ inch.

The lower longerons are $\frac{3}{4}$ by $\frac{3}{4}$ ash and the upper ones are $\frac{3}{4}$ by $\frac{3}{4}$ spruce.

The ski is attached to the axle by means of a bracket and bearing combined which slides on the axle the same is the wheel.

Figure 1 shows a cross-sectional view of the ski. The weight of the ski ready for use is $21\frac{1}{2}$ pounds.

PROCEDURE.

The ski was placed in an inverted position by a steel shaft passing through the bearing and supported on each side of it. A jack was placed at each end to prevent rotation during loading.

The load was applied in increments ranging from 2,000 pounds at the start of static test to 500 pounds at the end.

It was placed so that the ski was balanced on the steel shaft.

RESULTS.

Failure occurred with a load of 12,500 pounds. Figure 2 shows the resulting failure.

Before failure it supported six times the total weight of an SE-5 airplane, or 12 times the load upon it when the airplane is at rest.

The results obtained are satisfactory. The ski is strong enough to be in service for a while under various weather conditions and still function satisfactorily.

90770—22

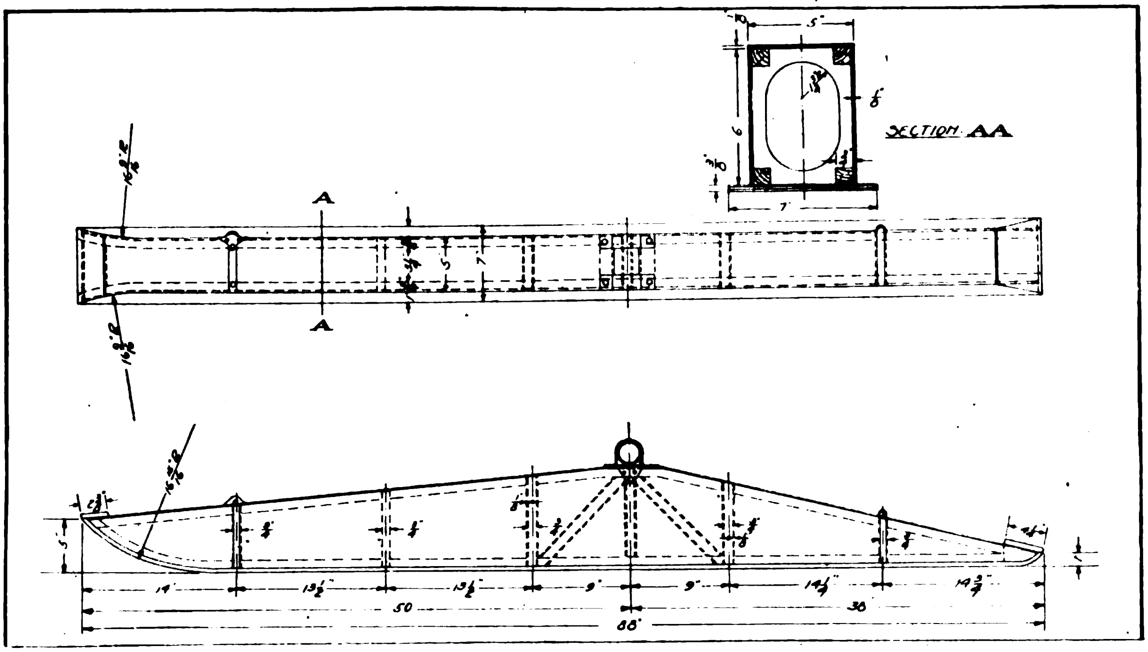


FIG. 1.—Landing ski for an SE-5 airplane.

FIG. 2.

McCOOK FIELD REPORT, SERIAL No. 1759

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV March 15, 1922 No. 323

REPORT ON AIRPLANE RADIO RECEIVING SET, TYPE SCR-59, REMODELED

(EQUIPMENT SECTION TEST REPORT)

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
October 4, 1921 7

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT ON AIRPLANE RADIO RECEIVING SET, TYPE SCR-59, REMODELED.

APPARATUS DEALT WITH.

The apparatus dealt with in this report is the airplane radio receiving set, type SCR-59. This set was intended originally to be used on airplanes where reception only was desired, and was to operate in conjunction with the airplane telephone set, type SCR-68, and the telephone set, type SCR-67. It was developed during the recent war by the Signal Corps, and was produced in quantities. The set box of this receiving set, designated as set box type BC-12, consists of a 3-tube receiving circuit using reactance coupling between the vacuum tubes.

NECESSITY FOR CHANGE IN DESIGN.

The SCR-59 receiver in its original form is very inefficient and requires the use of comparatively great power at the transmitting station to carry on communication over a given distance. The transmitting sets with which the Air Service is now supplied are of very low power. Due to the fact that the Signal Corps offers no immediate hope for the supply of any modern types of apparatus, it is necessary to improve the efficiency of existing types of apparatus so that the maximum possible range may be secured.

LIMITING FACTORS IN THE REDESIGN.

Due to limited funds available for this work it was necessary that the redesign should call for no great expenditure of time or money. It was considered necessary to limit the changes to those which could be easily accomplished by comparatively inexperienced instrument men, and to also limit the changes to those which could be made without making necessary additional apparatus outside of the original set box.

DESIGN ADOPTED.

The changes made in this redesigned receiving set are as follows:

(*a*) Substitution of transformer coupling for reactance coupling between the vacuum tubes.

(*b*) Addition of a tickler coil in the plate circuit of the detector tube.

(*c*) Substitution of nonrusting resistance wire on resistances, type RS-4, one of which is in the filament circuit of each vacuum tube.

The transformers used may be any type of audio frequency amplifying transformers such as made by several commercial firms, or the Signal Corps transformer type C-21. The use of transformer coupling between the tubes increases the efficiency of the receiving set to a marked degree. Signals which could not be heard when using the reactance coupling are made easily audible by means of transformer coupling. The use of a tickler coil in the plate circuit of the detector tube makes use of the Armstrong "feed-back" system and further amplifies the received signal. The use of nonrusting resistance wire on the resistance type RS-4 will correct a fault which has been present in a large number of the receiving sets, type SCR-59, issued to the service after a shelf life of about two years, namely, that of an opening in the filament circuit of one or more of the tubes due to the wire having rusted and broken.

The choke coils, type C-2, formerly used for coupling, have been removed from the set box and the transformers have been installed in their places. By means of a suitable mounting (the design of which depends upon the type of transformer used) the transformers are installed in the spaces made vacant by the coils. It is necessary to change the position of the antenna coil in the set box to permit the installation of the tickler coil. The method of mounting this coil is shown in figure 1. The construction of the tickler coil is shown in figure 2. The handle for operating this tickler coil has been extended through the front panel of the set box and a suitable knob has been provided to facilitate its operation. The knob for varying the antenna inductance has been removed due to the crowding on the face of the set box and a new type of handle has been substituted. The appearance of the set box after remodeling s shown in figure 3.

CONCLUSIONS.

The airplane radio receiving set, type SCR-59, when remodeled as described above, has greatly increased efficiency when used to receive damped wave signals. No reliable laboratory means for comparing signal intensity was at hand, so a flight test was arranged to learn the increase in range which might be expected when using the redesigned receiver. A spark transmitter working on reduced power was used at the ground station. A Curtiss JN-4 airplane was equipped with an SCR-59 receiver of the original type, and one of the remodeled type. A 200-foot trailing wire antenna was used. Signals from the ground station died out when the airplane was 1 mile from the transmitting station when using the standard model of the SCR-59 receiver. When using the remodeled SCR-59 receiver, but with the tickler coil set at zero coupling, the same signal was audible to a distance of 5 miles. When the tickler coil was adjusted for maximum sensitivity, the signal was audible at a distance of 18 miles. This serves to indicate the enormous improvement made by remodeling this set.

The addition of the tickler coil to this receiving set also makes possible the reception of undamped signals over the wave-length range of the set, which was not possible in the original receiver.

It is recommended that all airplane radio receiving sets, type SCR-59, be remodeled as described above before being sent from the various supply depots to the service. It is recommended that as soon as a sufficient number of receiving sets, type SCR-59, are remodeled they be sent to the service, and all unremodeled sets be returned to the supply depots, and that the original airplane radio telephone receiving set, type SCR-59, be considered obsolete.

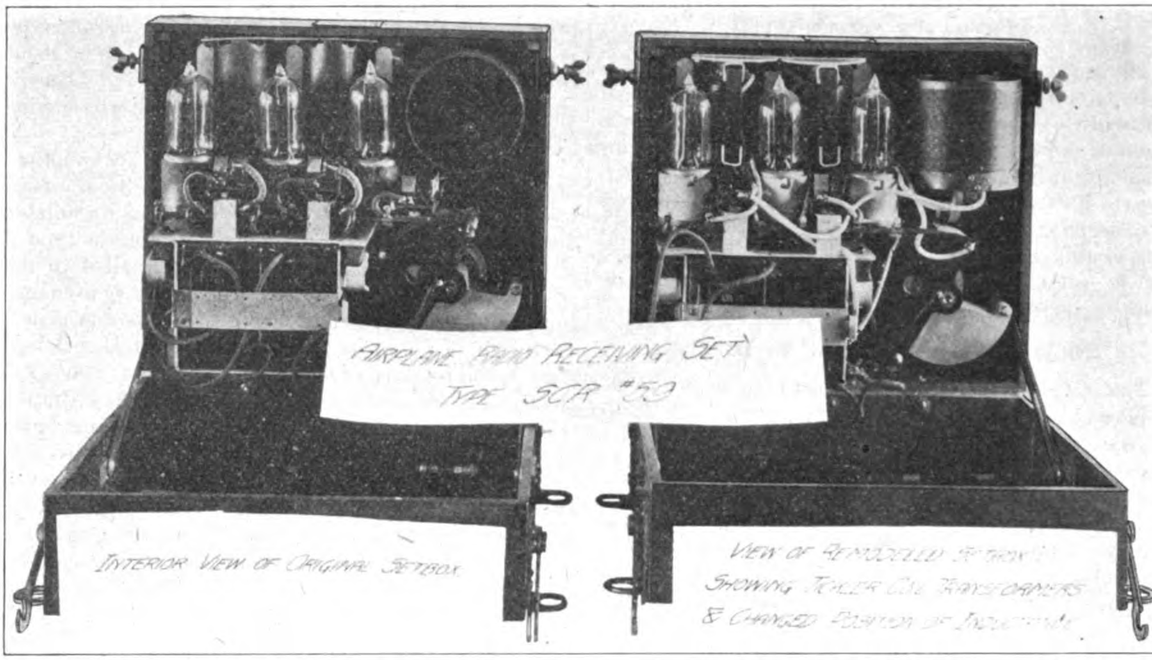
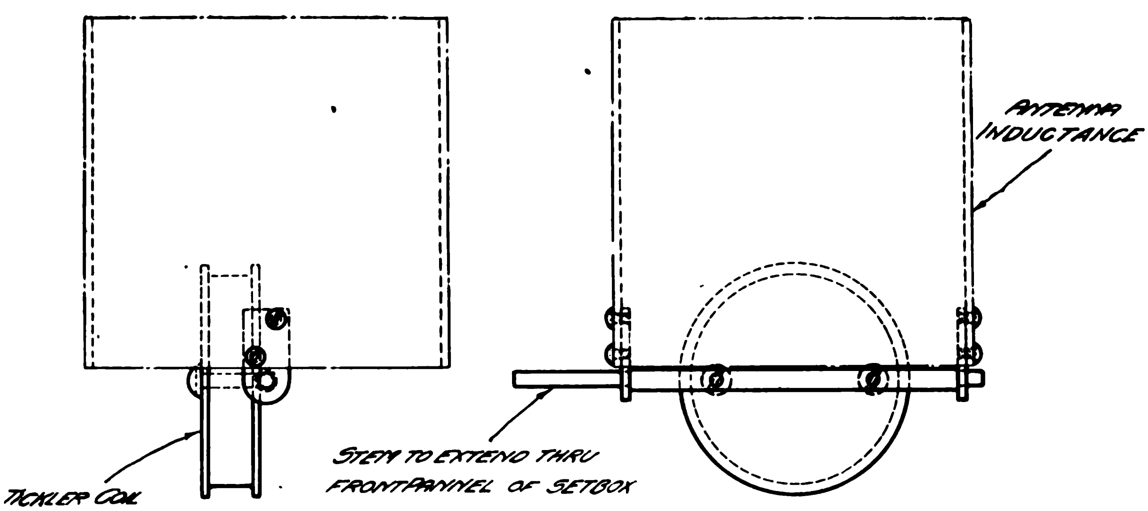


FIG. 1.



NOTE.—Tickler coil wound with 35 turns of No. 28 B. & S. gauge double cotton covered wire.

FIG. 2.—Method of mounting tickler coil in airplane radio receiving set, type SCR-59.

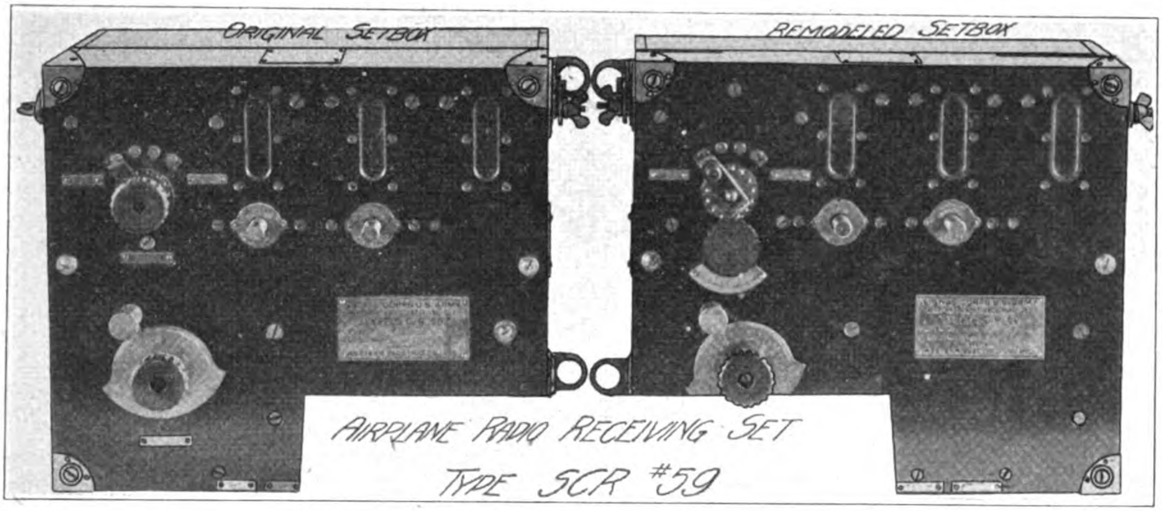


FIG. 3.

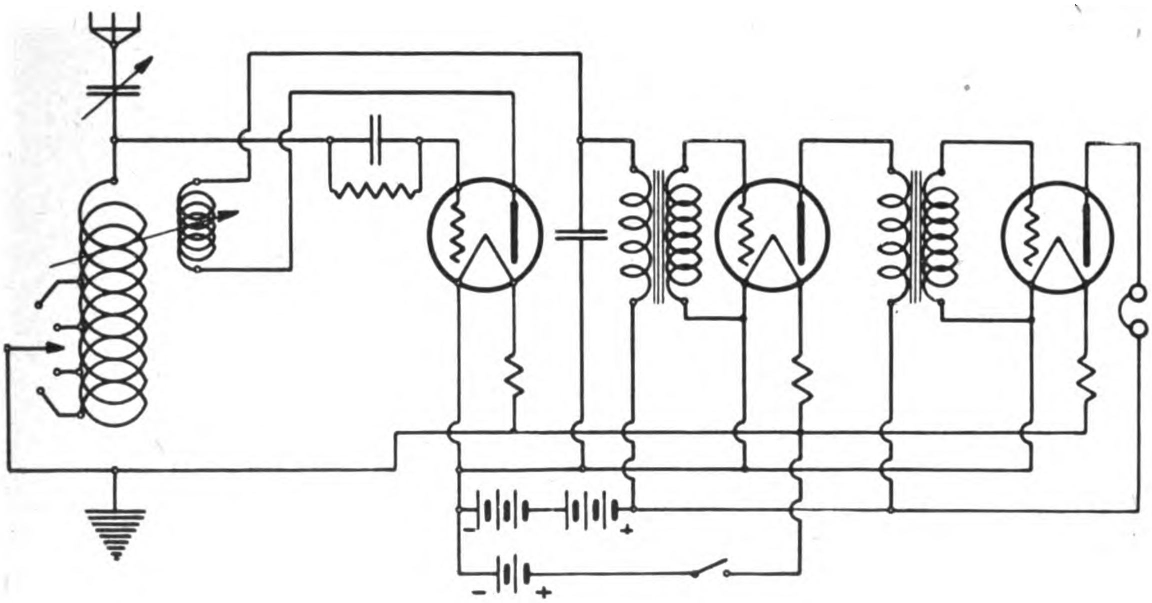


FIG. 4.—Wiring diagram of airplane receiving set, type SCR-59 remodeled.

[redacted]E ONLY

File D 52.41/Rausie/3

McCOOK FIELD REPORT, SERIAL No. 1760

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 324

FIFTY-HOUR ENDURANCE TEST OF RAUSIE E-6 AVIATION ENGINE

(POWER PLANT SECTION REPORT)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
October 13, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INDEX.

FIFTY-HOUR ENDURANCE TEST OF RAUSIE E-6 AVIATION ENGINE.

OBJECT OF TEST.

The object of this test was to determine the reliability and durability of a Rausie E-6, vertical, six-cylinder, water-cooled engine under practically service conditions.

SUMMARY.

This engine made a remarkably good showing throughout the 50-hour test. At no time was it necessary to make a forced stop because of minor or major failures. The power, fuel, and oil consumption remained unusually uniform. Not a single adjustment was made, except at one time to change the oil pressure slightly. The external appearance of the engine was very clean at the finish of the run, no cleaning having been done at any time.

The oil consumption was very low, the engine having consumed 12 gallons of oil for the entire test, which for the particular oil used amounted to less than 95 pounds.

The inspection after complete tear down brought to light the fact that very little wear had occurred at the various rubbing parts, despite the low oil consumption.

CONCLUSIONS.

The engine is recommended for training purposes with the changes suggested in this report.

DESCRIPTION OF ENGINE.

The Rausie E-6 aviation engine is a six-cylinder, vertical, water cooled engine manufactured by the Steel Products Co., Springfield, Ohio. The engine tested was the second design of the E-6 type, incorporating all the changes recommended in the Engineering Division report, serial No. 1430, Air Service Information Circular, Volume II, No. 191, on the first engine tested. A complete description of the redesigned engine will be found in the standard report which is now in the course of preparation, and in the report mentioned.

The characteristic features are: (*a*) Steel machined cylinders threaded at the upper end to screw into individual aluminum castings, these castings comprising the cylinder head, valve port, and water jackets, the lower ends of which fit against gaskets held in place by a flange on the steel cylinder; (*b*) A valve gear of novel design eliminating excessive side thrust on the valve stems and valve-stem guides.

METHOD OF CONDUCTING TEST.

In this test the usual calibration runs were made on the dynamometer.

The engine was mounted on a torque stand in the open air and fitted with a propeller designed to absorb the full power of the engine at the normal speed of 1,650 revolutions per minute.

The 50-hour endurance test was divided into ten periods of five hours each. The first half hour of each period was run at full throttle, and during the remaining four and one-half hours the engine was run at nine-tenths of full power, or practically 97 per cent, of the full throttle speed as determined by the propeller characteristics.

For a detailed description of the 50-hour endurance test and the methods used in computing the results, see power plant report, serial No. 1507.

INSPECTION AFTER TEST.

On completion of the test the engine was entirely disassembled and inspected. The condition of the engine on the whole was remarkably good.

The main and connecting rod bearings were in very good condition after a run of this duration. Figures 11 and 12 are photographs of the bearings.

The cam shaft showed wear on the noses of two cams due to insufficient lubrication caused by the lodging of dirt in the oil holes drilled in the face of the cams. See figure 9.

No. 6 exhaust cam follower was badly worn due to a lack of sufficient lubricating oil caused by dirt plugging the oil holes drilled in the face of the cam. See figure 9.

The cam shaft drive gears were all in excellent condition. The same was true of the accessories' drive gears.

The valve gear as a whole was in good condition. All valve stems were a very close fit in the guides. No valve springs were broken and all the valve springs retained practically their original compression. The exhaust valves and seats were badly pitted. All exhaust valves leaked more or less on the gasoline test at the completion of the test. No. 3 exhaust valve leaked gasoline freely. All the inlet valves were tight.

Valve timing and valve clearances before and after 50-hour endurance test.

	Cylinder No. 1.	Cylinder No. 2.	Cylinder No. 3.	Cylinder No. 4.	Cylinder No. 5.	Cylinder No. 6.
Inlet opens (before)	11° A. T. C.	11° A. T. C.	10° A. T. C.	11° A. T. C.	10° A. T. C.	11° A. T. C.
Inlet opens (after)	9° A. T. C.	10° A. T. C.	8° A. T. C.	10° A. T. C.	7° A. T. C.	10° A. T. C.
Inlet closes (before)	36° A. B. C.	38° A. B. C.	40° A. B. C.	39° A. B. C.	39° A. B. C.	39° A. B. C.
Inlet closes (after)	40° A. B. C.	40° A. B. C.	42° A. B. C.	42° A. B. C.	42° A. B. C.	42° A. B. C.
Exhaust opens (before)	45° B. B. C.	45° B. B. C.	43° B. B. C.	45° B. B. C.	45° B. B. C.	43° B. B. C.
Exhaust opens (after)	65° B. B. C.	53° B. B. C.	62° B. B. C.	55° B. B. C.	50° B. B. C.	58° B. B. C.
Exhaust closes (before)	17° A. T. C.	18° A. T. C.	16° A. T. C.	18° A. T. C.	17° A. T. C.	16° A. T. C.
Exhaust closes (after)	45° A. T. C.	32° A. T. C.	36° A. T. C.	35° A. T. C.	30° A. T. C.	37° A. T. C.
Inlet clearance (before)	0.020 inch	0.020 inch	0.020 inch	0.019 inch	0.019 inch	0.019 inch.
Inlet clearance (after)	do	0.021 inch	do	do	0.017 inch	Do.
Exhaust clearance (before)	0.019 inch	0.020 inch	0.021 inch	0.020 inch	0.019 inch	0.020 inch.
Exhaust clearance (after)	0.004 inch	0.007 inch	None	0.007 inch	0.010 inch	0.019 inch.

It is interesting to note the slight variation in clearance that took place in the inlet valve timing and clearances. The decreased clearances on the exhaust valves with a consequent greater period of valve opening had practically no effect on the power output as will be noted on the log sheets.

The magneto timing was set at 30° advance. The wear at the magneto drive coupling reduced the advance to 28° at the finish of the run. This decrease was due to wear which occurred on the squared portion of the female member of the coupling assembly. No wear took place at the serrations.

ANALYSIS.

This engine made an excellent showing on the test. No forced stops were made and the power output was very uniform. The speed and power at the finish of the tenth period remained as uniform as it was during any of the other periods. The fuel and oil consumption on test was very good. The oil pressure was changed twice during the test. An increase in pressure did not materially increase the consumption, as will be noted on the log.

The condition of the main and connecting rod bearings was excellent after a run of this duration. The bearings were in such good condition that much more running would have been easily possible.

Several cams showed undue wear. This was found to be due to dirt lodging in the oil holes which are drilled through the faces of the cams. Insufficient lubrication at these points resulted in undue wear on the corresponding cam followers.

The magneto couplings developed undue wear which resulted in backlash considerably in excess of that which was present at the beginning.

The cylinder construction is not very sound thermally, as the condition of the valves showed, since it requires heat conduction through metal surfaces not held rigidly in contact. This could be improved by the provision of means to insure a better contact between the steel barrel and the aluminum jacket and a thicker combustion chamber head. An alternative and perhaps more satisfactory construction would be such as is used in the B. H. P. engine in which the barrel is of steel but open at the combustion chamber end, permitting a combustion chamber of aluminum in which the heat has only one metal to pass through to the cooling water. In this construction the valve seats are of bronze "expanded" in with a tool similar to that used in expanding boiler tubes.

The valve gear requires care in assembly, and once assembled the clearances can not be adjusted without removal of the entire cam shaft assembly. In this connection it is well to note the change in tappet clearances (and consequently in timing) which occurs after extended running. (See tear-down inspection.)

RECOMMENDATIONS.

The following changes are recommended in future engines of this model:

(*a*) Increase diameter of crank-pin oil plug bolts. The present ones appear too light, which might cause undue stretching with a consequent loosening of the plug in its seat.

(*b*) Increase size of engine to engine-bearer hold down bolts and holes. These bolts did not work loose or break, but a larger size is considered advisable. Provide castellated nuts on oil pump case studs. Also provide castellated nuts on water pump studs.

(*c*) The thickness of the web of the connecting rod can be decreased, thereby cutting down the weight without undue sacrifice of strength.

(*d*) Increase thickness of combustion chamber heads and, if practicable, improve contact with aluminum jackets by means of two studs. If studs can not be used, heads should be fitted to bear first at the center between the valves. The cylinder valve ports could be cleaned up by shortening up on the valve stem guides which project into the ports on one end. Also recommend placing the spark plugs 180° apart and at right angles to the crankshaft center lines.

(*e*) A good quality sheet cork gasket should be placed between the cam-shaft housing and the cylinder head. The cam followers should be shortened to eliminate the tendency to pump oil. This pumping action is perhaps caused by the follower passing over the gasket. It may be of advantage to increase the size of the oil holes in the face of the cams and the size of the oil passage into the cam shaft in order to reduce possibility of oil holes in cams becoming plugged.

(*f*) Counterbore the crankshaft gear to prevent starter marring the splines and make the splines even.

(*g*) The magneto coupling design should be improved to eliminate the tendency to wear. If the square type of drive is retained, the area of the female and male members should be increased and carefully hardened.

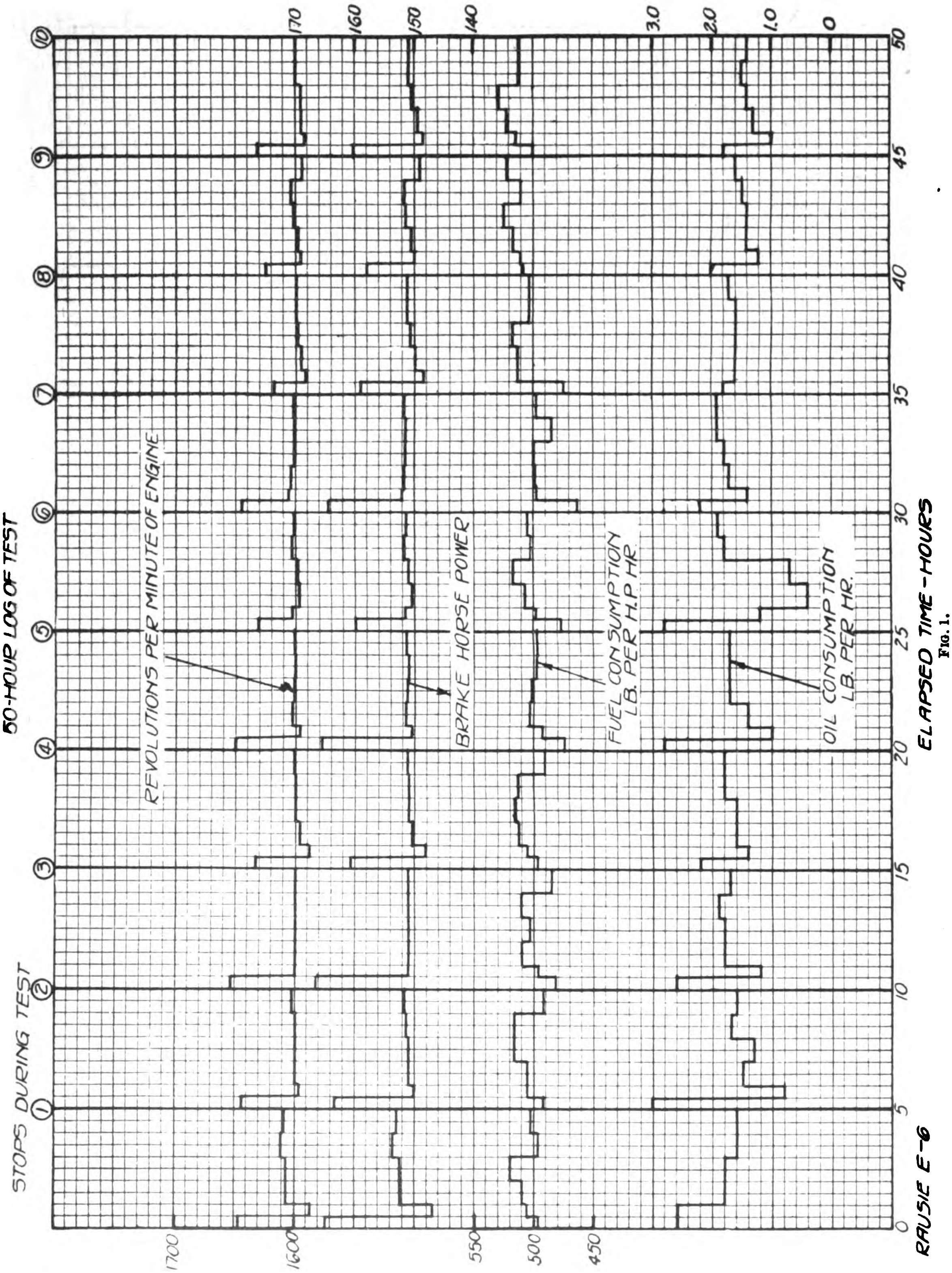

50-HOUR LOG OF TEST
STOPS DURING TEST
1 2 3 4 5 6 7 8 9 10
REVOLUTIONS PER MINUTE OF ENGINE
BRAKE HORSE POWER
FUEL CONSUMPTION LB. PER H.P. HR.
OIL CONSUMPTION LB. PER HR.
1700 1600 550 500 450
170 160 150 140
3.0 2.0 1.0 0
0 5 10 15 20 25 30 35 40 45 50
ELAPSED TIME - HOURS
RAUSIE E-6

Fig. 1.

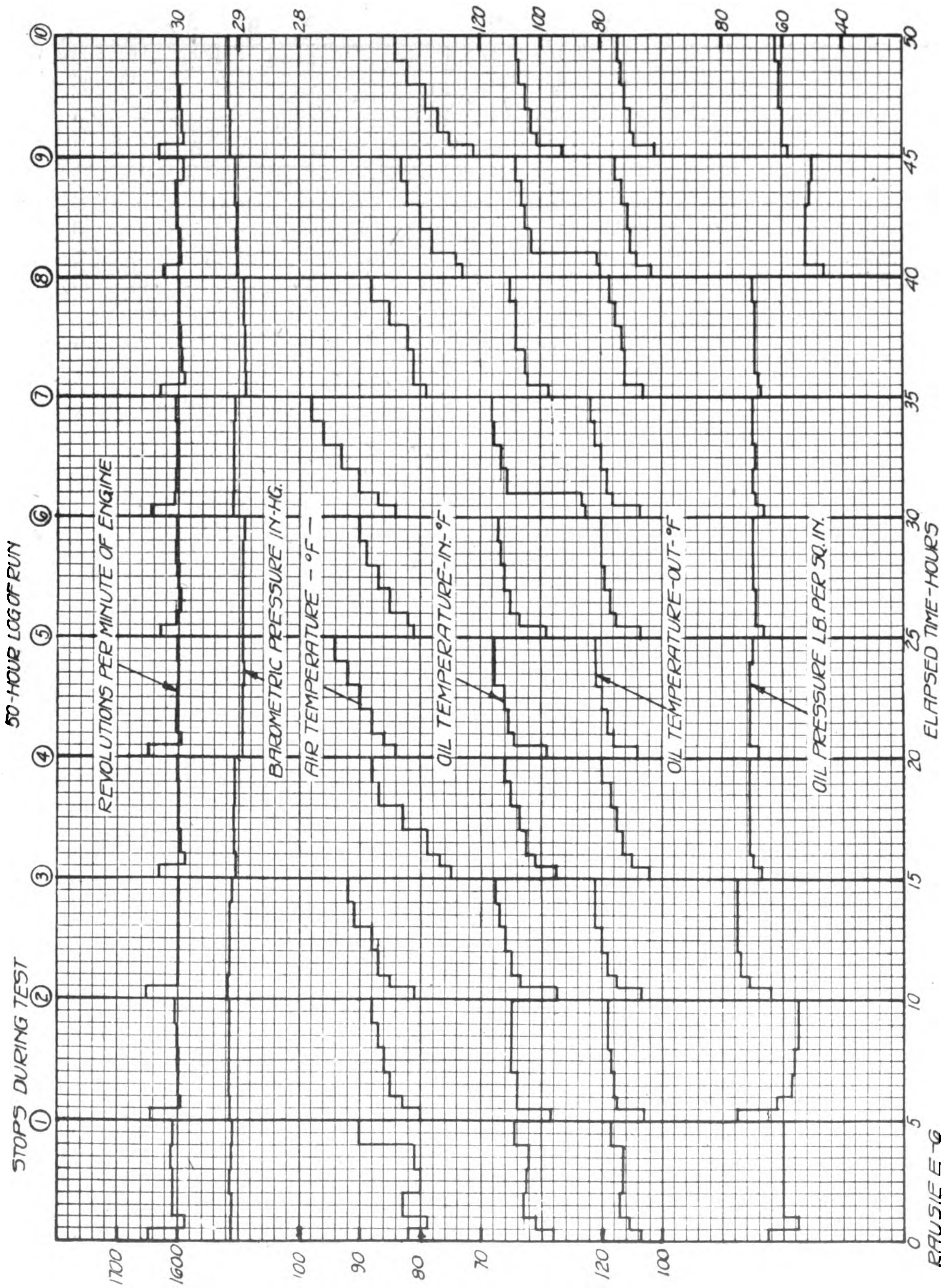

50-HOUR LOG OF RUN
STOPS DURING TEST
REVOLUTIONS PER MINUTE OF ENGINE
BAROMETRIC PRESSURE IN-HG.
AIR TEMPERATURE - °F -
OIL TEMPERATURE-IN-°F
OIL TEMPERATURE-OUT-°F
OIL PRESSURE LB. PER SQ. IN.
ELAPSED TIME-HOURS
RAUSIE E-G

Fig. 2.

Average of averages of first half hour runs (Rausie E-6).

FULL THROTTLE.

R. P. M. of engine.	B. H. P.	Air temp. °F.	Bar. In./Hg.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. In.	Oil. Temp., °F. Out.	Oil. Press., lb. per sq. in.	Man. vac., in. Hg.	Fuel cons. Lb. per hr.	Fuel cons. Lb. per hp. hr.	Oil cons. Lb. per hr.
1,638	162.2	79	29.05	142	150	93	105	64	1.4	79.0	.487	2.4

Average of averages of last four and one-half hour runs.

PARTIAL THROTTLE.

1,600	150.8	85	29.05	143	150	108	116	65	2.0	76.8	.506	1.5

Table of average results.

Date.	Time. Total elapsed. Hr.	Time. Total elapsed. Min.	Time. Duration this run. Hr.	Time. Duration this run. Min.	R. P. M. of engine.	B. H. P.	Carb. air, Temp., °F.	Bar., in. Hg.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. In.	Oil. Temp., °F. Out.	Oil. Press., lb. per sq. in.	Man. vac., in. Hg.	Carb. vac., in. Hg.	Fuel Cons. Lb. per hr.	Fuel Cons. Lb. per hp. hr.	Oil cons., lb. per hr.
July 8, 1921	0	30	0	30	[1] 1,648	165.0	82	29.12	142	150	96	107	65	1.4	1.6	82.0	0.497	2.6
	1	00	0	30	1,587	147.0	79	29.12	143	150	102	111	55	2.1	1.3	74.5	.507	2.6
	2	00	1	00	1,607	152.5	83	29.11	143	150	106	114	60	1.9	1.3	77.8	.510	1.8
	3	00	1	00	1,607	152.5	80	29.12	142	150	105	113	60	1.9	1.3	79.3	.520	1.8
	4	00	1	00	1,610	153.5	81	29.10	144	151	104	113	60	2.0	1.3	76.3	.497	1.6
	5	00	1	00	1,608	153.0	90	29.09	143	150	109	117	60	2.0	1.3	77.0	.503	1.6
Stop—End of first period.																		
July 11, 1921	5	30	0	30	[1] 1,643	163.5	80	29.13	143	151	97	106	75	1.4	....	80.5	0.492	3.0
	6	00	0	30	1,597	150.0	83	29.13	143	150	108	115	62	2.1	....	76.0	.506	.8
	7	00	1	00	1,600	151.0	85	29.14	143	150	108	116	57	2.1	....	76.5	.506	1.5
	8	00	1	00	1,600	151.0	86	29.14	143	150	110	117	56	2.1	....	78.0	.516	1.3
	9	00	1	00	1,601	151.2	87	29.14	143	150	110	118	55	2.1	....	78.0	.516	1.7
	10	00	1	00	1,603	151.5	88	29.14	143	151	110	118	55	2.1	....	74.8	.493	1.6
Stop—End of second period.																		
July 12, 1921	10	30	0	30	[1] 1,653	166.5	81	29.17	144	152	95	107	64	1.5	....	80.5	0.483	2.6
	11	00	0	30	1,600	151.0	85	29.17	143	150	107	115	71	2.2	....	75.0	.497	1.2
	12	00	1	00	1,600	151.0	87	29.15	143	150	110	118	74	2.1	....	77.0	.510	1.8
	13	00	1	00	1,600	151.0	88	29.15	143	150	112	120	75	2.1	....	76.0	.503	1.8
	14	00	1	00	1,600	151.0	91	29.15	145	152	114	122	75	2.0	....	77.0	.510	1.9
	15	00	1	00	1,600	151.0	92	29.12	143	150	115	122	75	2.1	....	73.3	.485	1.7
Stop—End of third period.																		
July 13, 1921	15	30	0	30	[1] 1,633	160.5	75	29.04	143	151	95	104	67	1.4	....	80.0	0.498	2.2
	16	00	0	30	1,589	148.0	77	29.04	142	149	102	110	70	2.2	....	75.0	.506	1.4
	17	00	1	00	1,597	150.0	79	29.06	143	150	105	113	71	2.0	....	76.8	.512	1.6
	18	00	1	00	1,600	151.0	83	29.07	143	151	107	115	71	2.0	....	77.8	.515	1.6
	19	00	1	00	1,600	151.0	87	29.06	142	150	110	117	71	2.1	....	77.3	.512	1.8
	20	00	1	00	1,601	151.2	88	29.06	142	150	112	120	71	2.2	....	74.0	.490	1.8
Stop—End of fourth period.																		

[1] One-half hour full throttle runs.

Table of average results—Continued.

Date.	Time. Total elapsed. Hr.	Time. Total elapsed. Min.	Time. Duration this run. Hr.	Time. Duration this run. Min.	R. P. M. of engine.	B. H. P.	Carb. air Temp., °F.	Bar. in. Hg.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. In.	Oil. Temp., °F. Out.	Oil. Press., lb. per sq. in.	Man. vac., in. Hg.	Carb. vac., in. Hg.	Fuel Cons. Lb. per hr.	Fuel Cons. Lb. per hp. hr.	Oil cons., lb. per hr.
July 14, 1921	20	30	0	30	[1] 1,650	165.5	84	28.96	141	150	98	108	68	1.4	....	78.5	0.474	2.8
	21	00	0	30	1,598	150.5	86	28.96	142	150	109	116	71	2.2	....	74.0	.491	1.0
	22	00	1	00	1,602	151.5	88	28.96	142	150	111	118	71	2.1	....	76.3	.503	1.4
	23	00	1	00	1,601	151.2	90	28.96	142	150	112	120	71	2.1	....	76.0	.502	1.7
	24	00	1	00	1,600	151.0	92	28.95	142	150	115	122	71	2.0	....	75.3	.498	1.7
	25	00	1	00	1,601	151.2	94	28.96	143	151	115	122	70	2.1	....	75.0	.496	1.7
Stop—End of fifth period.																		
July 15, 1921	**25**	**30**	**0**	**30**	**[1] 1,631**	**160.0**	**81**	**28.96**	**141**	**150**	**98**	**107**	**66**	**1.4**	....	**76.5**	**0.478**	**2.8**
	26	**00**	**0**	**30**	**1,602**	**151.5**	**82**	**28.96**	**142**	**150**	**107**	**115**	**69**	**2.0**	....	**75.5**	**.498**	**1.2**
	27	**00**	**1**	**00**	**1,598**	**150.5**	**85**	**28.96**	**143**	**151**	**110**	**117**	**69**	**2.0**	....	**76.5**	**.508**	**.4**
	28	**00**	**1**	**00**	**1,599**	**150.8**	**87**	**28.96**	**142**	**151**	**112**	**119**	**70**	**2.0**	....	**78.0**	**.517**	**.7**
	29	**00**	**1**	**00**	**1,602**	**151.5**	**89**	**28.96**	**142**	**150**	**113**	**120**	**70**	**2.0**	....	**76.0**	**.501**	**1.8**
	30	**00**	**1**	**00**	**1,601**	**151.2**	**90**	**28.94**	**142**	**150**	**114**	**120**	**70**	**2.0**	....	**76.3**	**.504**	**1.9**
Stop—End of sixth period.																		
July 18, 1921	**30**	**30**	**0**	**30**	**[1] 1,646**	**164.5**	**84**	**29.09**	**142**	**150**	**85**	**107**	**66**	**1.4**	....	**76.0**	**0.462**	**2.2**
	31	**00**	**0**	**30**	**1,605**	**152.0**	**87**	**29.09**	**144**	**152**	**86**	**116**	**69**	**2.2**	....	**75.5**	**.497**	**1.4**
	32	**00**	**1**	**00**	**1,603**	**151.5**	**90**	**29.08**	**140**	**148**	**111**	**118**	**70**	**2.1**	....	**75.5**	**.498**	**1.7**
	33	**00**	**1**	**00**	**1,601**	**151.2**	**93**	**29.08**	**142**	**150**	**113**	**120**	**69**	**2.2**	....	**75.5**	**.499**	**1.8**
	34	**00**	**1**	**00**	**1,601**	**151.2**	**96**	**29.08**	**141**	**149**	**115**	**122**	**70**	**2.2**	....	**73.3**	**.485**	**1.9**
	35	**00**	**1**	**00**	**1,602**	**151.5**	**98**	**29.07**	**142**	**150**	**116**	**123**	**70**	**2.2**	....	**75.3**	**.497**	**1.9**
Stop—End of seventh period.																		
July 19, 1921	**35**	**30**	**0**	**30**	**[1] 1,629**	**159.0**	**79**	**28.88**	**144**	**151**	**97**	**106**	**67**	**1.4**	....	**75.5**	**0.475**	**1.8**
	36	**00**	**0**	**30**	**1,592**	**148.5**	**81**	**28.88**	**143**	**151**	**104**	**112**	**68**	**1.9**	....	**76.0**	**.512**	**1.6**
	37	**00**	**1**	**00**	**1,596**	**150.0**	**81**	**28.90**	**143**	**151**	**105**	**112**	**69**	**1.9**	....	**76.8**	**.512**	**1.6**
	38	**00**	**1**	**00**	**1,598**	**150.5**	**82**	**28.90**	**143**	**151**	**108**	**113**	**69**	**1.8**	....	**78.0**	**.518**	**1.6**
	39	**00**	**1**	**00**	**1,600**	**151.0**	**85**	**28.92**	**143**	**150**	**108**	**115**	**69**	**1.9**	....	**76.0**	**.503**	**1.6**
	40	**00**	**1**	**00**	**1,600**	**151.0**	**88**	**28.92**	**143**	**151**	**110**	**117**	**70**	**1.9**	....	**76.0**	**.503**	**1.7**
Stop—End of eighth period. Oil pressure decreased.																		
July 20, 1921	**40**	**30**	**0**	**30**	**[2] 1,625**	**158.0**	**73**	**29.01**	**143**	**150**	**80**	**103**	**46**	**1.4**	....	**80.5**	**0.509**	**2.0**
	41	**00**	**0**	**30**	**1,596**	**150.0**	**74**	**29.01**	**143**	**150**	**81**	**108**	**52**	**1.8**	....	**76.5**	**.510**	**1.2**
	42	**00**	**1**	**00**	**1,597**	**150.5**	**78**	**29.01**	**142**	**150**	**103**	**110**	**52**	**1.8**	....	**77.8**	**.517**	**1.4**
	43	**00**	**1**	**00**	**1,601**	**151.2**	**80**	**29.01**	**143**	**150**	**105**	**111**	**52**	**1.8**	....	**79.5**	**.526**	**1.4**
	44	**00**	**1**	**00**	**1,602**	**151.5**	**82**	**29.02**	**144**	**151**	**106**	**113**	**51**	**1.8**	....	**77.3**	**.510**	**1.5**
	45	**00**	**1**	**00**	**1,594**	**149.0**	**83**	**29.02**	**142**	**150**	**108**	**115**	**50**	**1.8**	....	**77.5**	**.520**	**1.6**
Stop—End of ninth period—Oil pressure increased.																		
July 21, 1921	45	30	0	30	[2] 1,631	160.0	71	29.14	142	150	93	102	58	1.4	....	80.0	0.500	1.8
	46	00	0	30	1,592	148.5	75	29.14	141	149	101	109	60	1.6	....	76.5	.515	1.0
	47	00	1	00	1,595	149.5	77	29.14	143	150	103	110	60	1.8	....	78.0	.522	1.3
	48	00	1	00	1,597	150.2	79	29.15	142	150	105	112	61	1.8	....	79.5	.529	1.4
	49	00	1	00	1,600	151.0	82	29.15	142	150	107	114	61	1.8	....	77.3	.512	1.5
	50	00	1	00	1,600	151.0	84	29.15	143	150	108	115	62	1.9	....	77.3	.512	1.4
	51	00	1	00	[2] 1,626	158.2	85	29.13	141	150	110	116	62	1.4	....	81.5	.516	1.6
	51	15	0	15	[2] 1,633	160.5	86	29.13	163	[3] 170	110	118	62	1.4	....	80.0	.498	1.2

Stop—End of test.

[1] One-half hour full throttle runs.
[2] Full throttle runs.
[3] The outlet water temperature was raised to 170° to determine the effect of increased water temperature on the heating of the valves. No bad effect noted, rather a slight improvement observed in power output.

The engine was run one hour over the regular 50 hours, the fifty-first hour being run at full throttle full power.

The acceleration, idling, and starting at the finish of the test were very good.

Calibration and friction H. P. runs on dynamometer.

R. P. M. of engine.	Actual.			Corrected.			Water.		Oil.			Carb. air, temp., ° F.	Man. vac., in. Hg.	Carb. vac., in. Hg.	Fuel cons.	
	Brake load, lb.	Torque, lb./ft.	B. H. P.	Torque, lb./ft.	H. P.	B.M.E. P., lb. per sq. in.	Temp., ° F. In.	Temp., ° F. Out.	Temp., ° F. In.	Temp., ° F. Out.	Press., lb. per sq. in.				Lb. per hr.	Lb. per hp. hr.
1,240	286	500.8	118.2	519.0	122.5	110.7	145	162	110	112	48	94	0.6	0.65	59.4	0.502
1,350	286	500.8	128.7	519.0	133.4	110.7	146	160	114	118	50	94	.7	.7	64.3	.499
1,440	287	502.2	137.7	521.0	142.7	111.2	146	160	116	120	50	96	.9	.9	69.2	.501
1,550	296	518.0	152.9	537.0	158.5	114.5	146	160	120	124	52	98	.9	1.0	76.1	.498
1,660	290	507.7	160.5	526.0	166.4	112.3	146	160	120	124	54	97	1.0	1.0	82.5	.514
1,740	284	497.0	164.7	515.3	170.7	110.0	144	160	122	125	55	95	1.3	1.1	85.0	.516
1,850	274	479.5	168.9	497.0	175.0	106.0	148	160	124	127	55	96	1.5	1.15	88.6	.525
1,950	259	453.4	168.4	470.0	174.5	100.3	147	160	125	130	56	96	1.7	1.2	92.4	.549

Bad oil leaks between cam-shaft housing and cylinder heads.
Length of brake arm, 21 inches; kind of oil used, U. S. Spec. 2-23b; specific gravity of fuel, .715 at 60° F.; average barometer, 28.88 in. Hg.

R. P. M. by tachometer.	Corrected engine B. H. P. from curve.	Friction load in pounds.	F. H. P.	Per cent mechanical efficiency.	Comp. press., lb. per sq. in.	Temperatures ° F.				
						Water. In.	Water. Out.	Oil. In.	Oil. Out.	Air.
1,230	121.7	28	11.5	91.4	....	162	162	128	132	96
1,340	132.5	34	15.2	89.8	....	160	162	128	130	96
1,430	143.5	43	20.5	87.6	....	158	160	128	132	94
1,540	156.0	45	23.1	87.2	....	158	160	127	132	94
1,650	165.5	50	27.5	85.8	....	158	160	126	132	94
1,750	171.5	52	30.3	85.0	....	158	160	126	130	93
1,840	174.2	54	33.1	84.0	....	160	162	126	130	94
1,960	174.8	56	36.6	82.7	....	160	162	128	132	94

Carburetors used, Stromberg NA-S5; chokes, 1½ inches; main jets, No. 50 drill size; flow, 44 pints per hour.
Length of brake arm, 21 inches; kind of oil used, U. S. Spec. 2-23b; average barometer, 28.88 in. Hg.

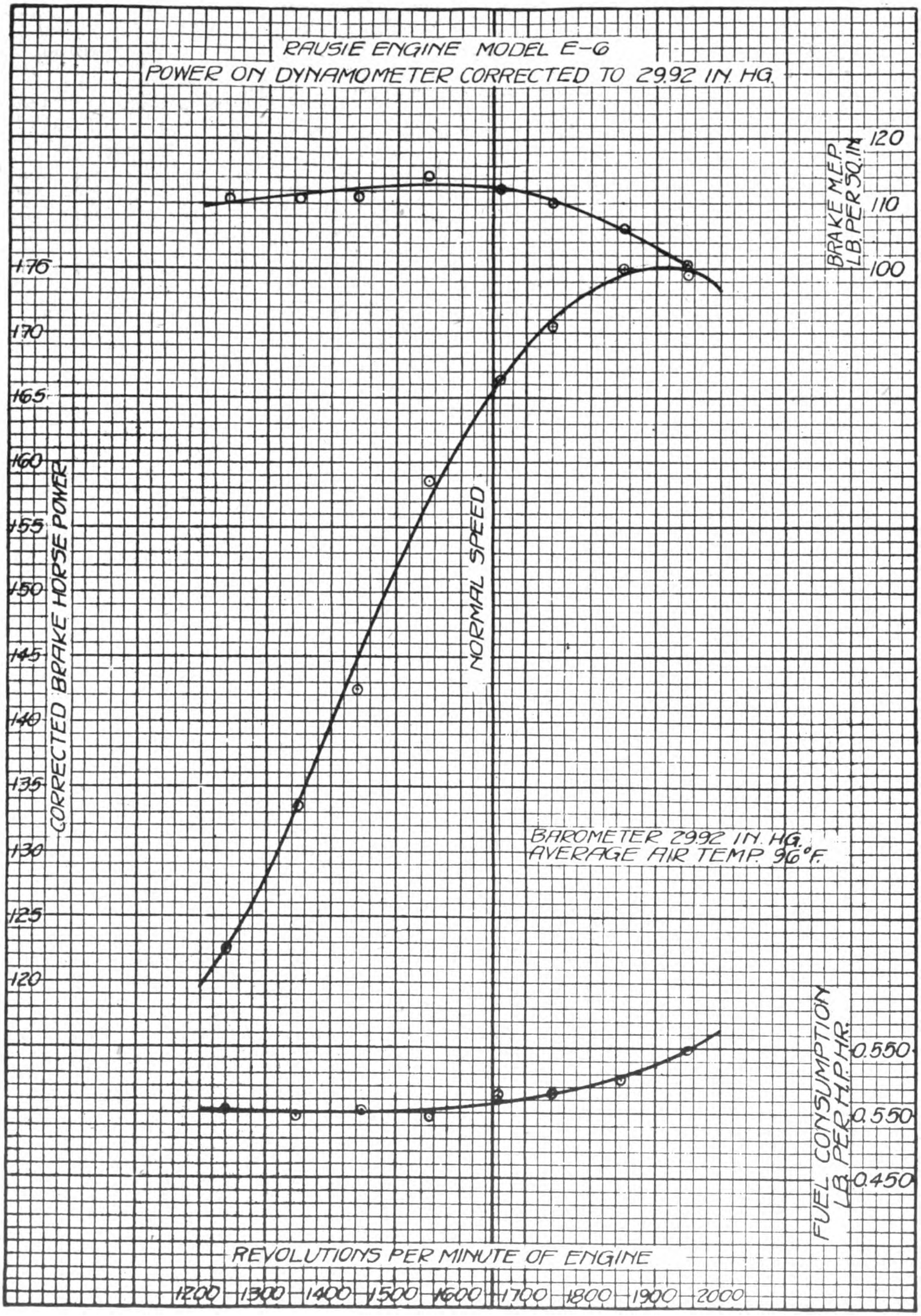

RAUSIE ENGINE MODEL E-6
POWER ON DYNAMOMETER CORRECTED TO 29.92 IN. HG.
BRAKE M.E.P. LB. PER SQ. IN.
120
110
100
176
170
165
160
155
150
145
140
135
130
125
120
CORRECTED BRAKE HORSE POWER
NORMAL SPEED
BAROMETER 29.92 IN. HG.
AVERAGE AIR TEMP. 96°F.
FUEL CONSUMPTION LB. PER H.P. HR.
0.550
0.550
0.450
REVOLUTIONS PER MINUTE OF ENGINE
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIG. 3.

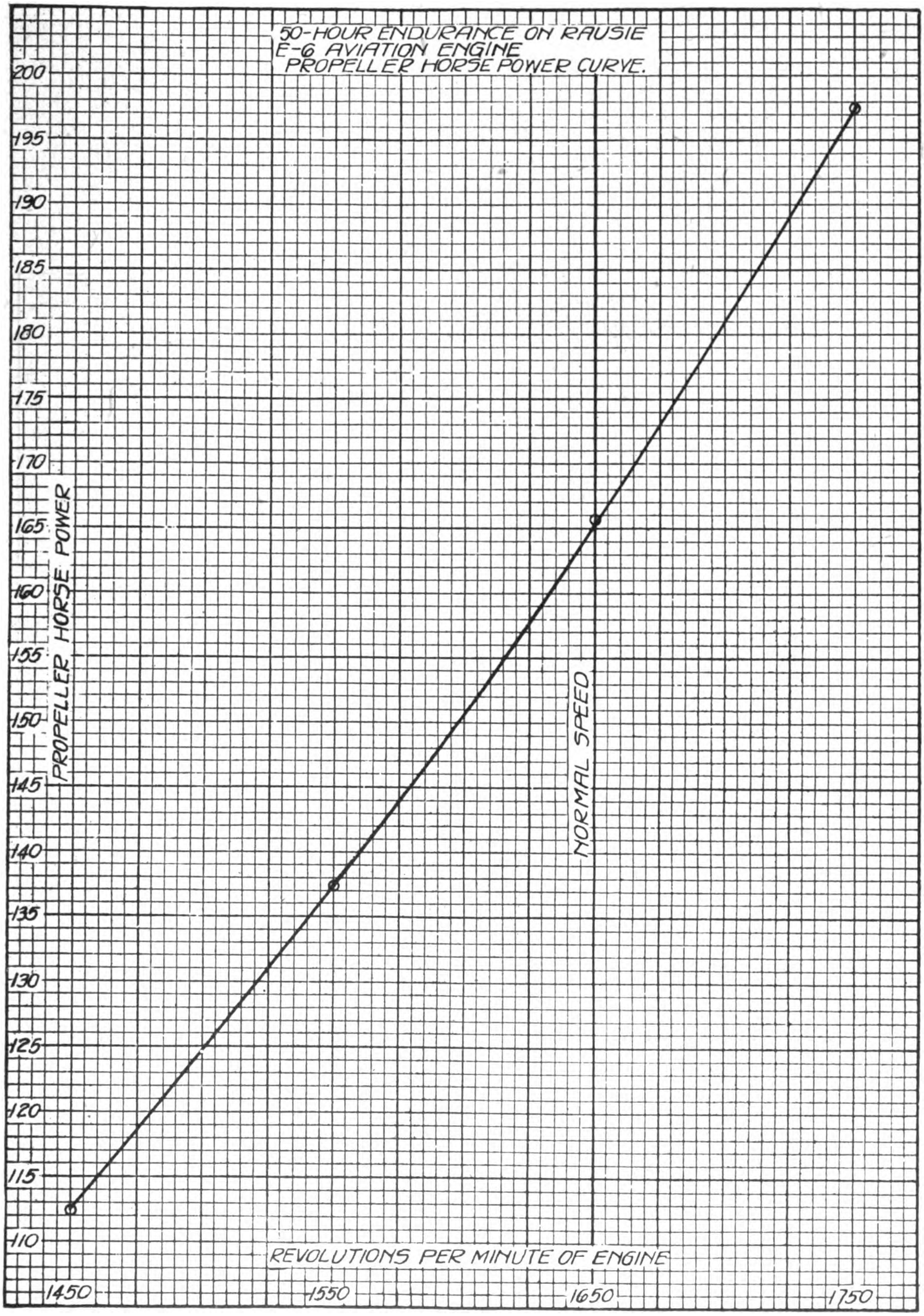

50-HOUR ENDURANCE ON RAUSIE
E-6 AVIATION ENGINE
PROPELLER HORSE POWER CURVE.
PROPELLER HORSE POWER
NORMAL SPEED
REVOLUTIONS PER MINUTE OF ENGINE
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
1450
1550
1650
1750

FIG. 4.

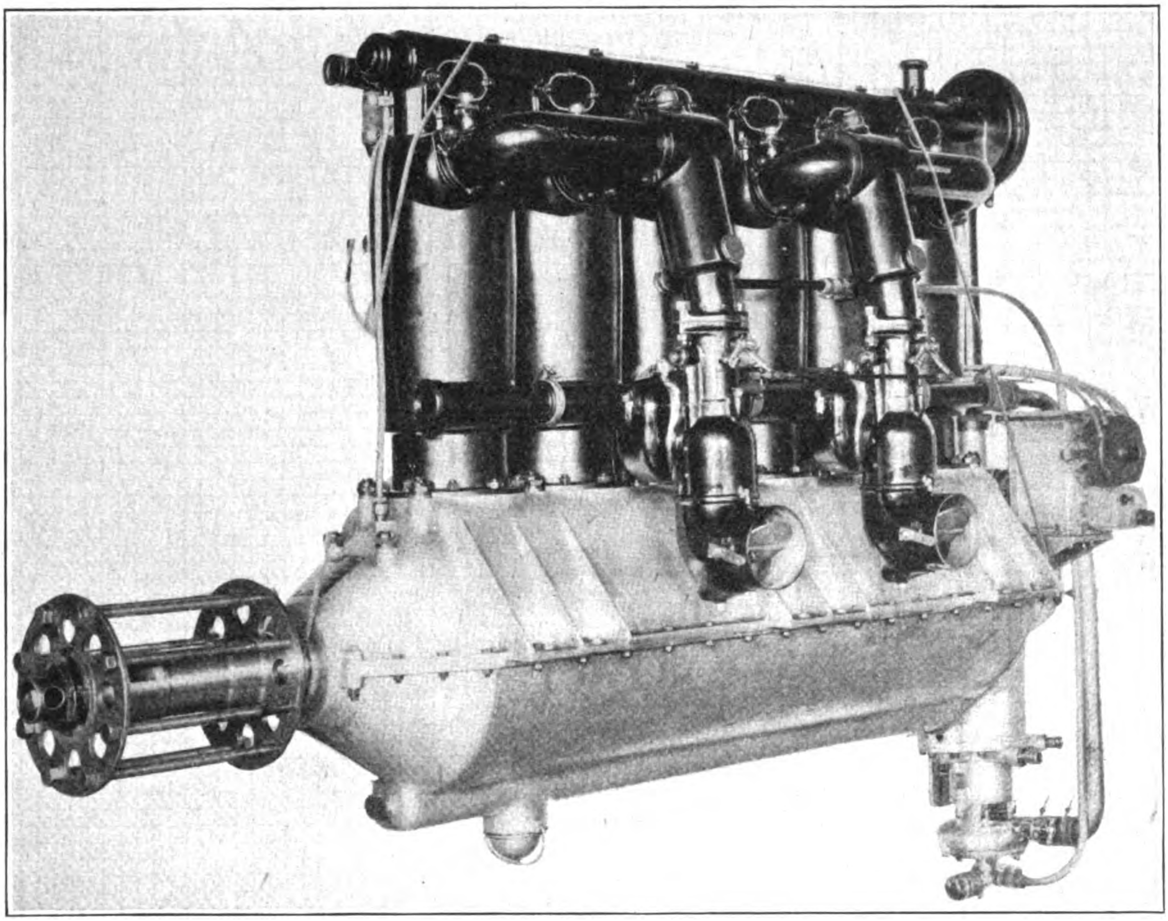


Fig. 5.—Three-quarter front view of engine.

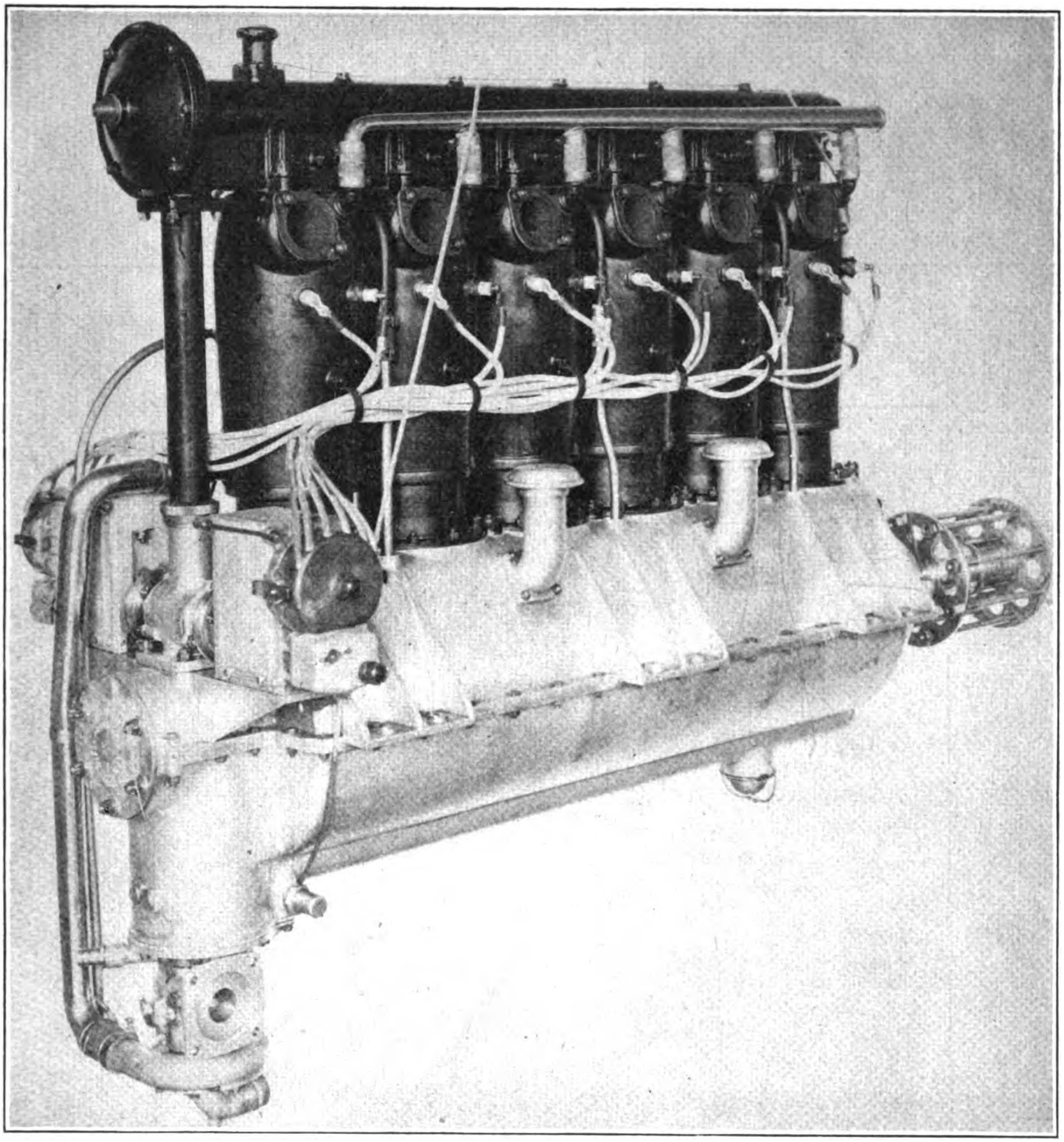


Fig. 6.—Three-quarter rear view of engine.

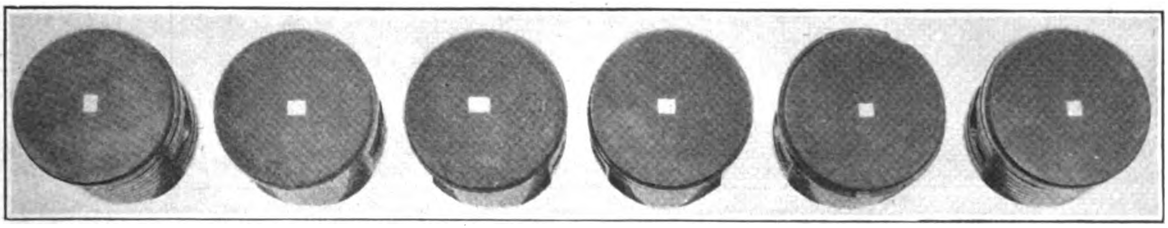


Fig. 7.—Pistons after finish of test.

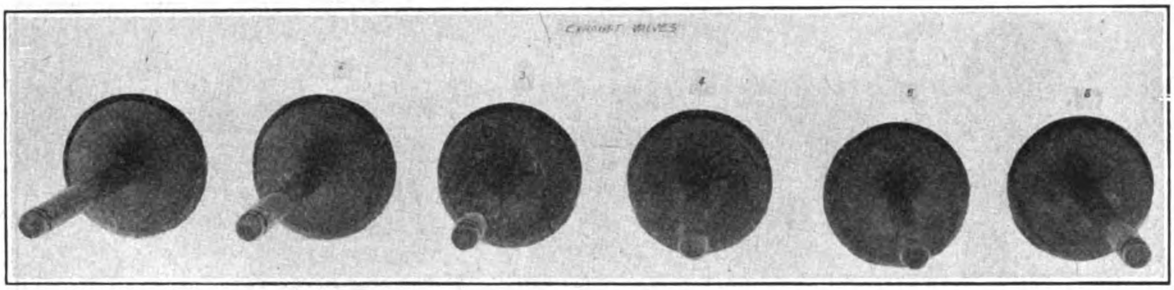


FIG. 8.—Exhaust valves after finish of 50-hour test.

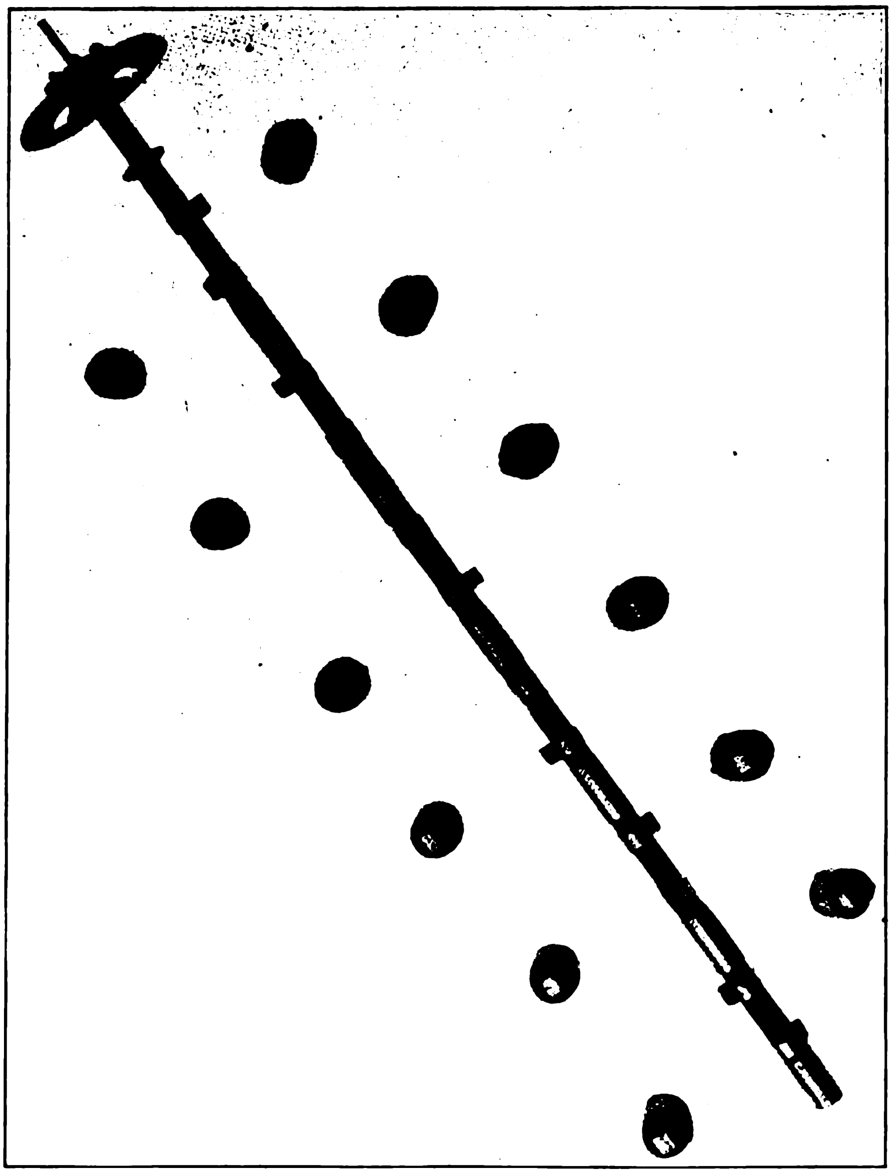


FIG. 9.—Camshaft and cam followers after 50-hour test. Note wear on No. 6 cam follower.

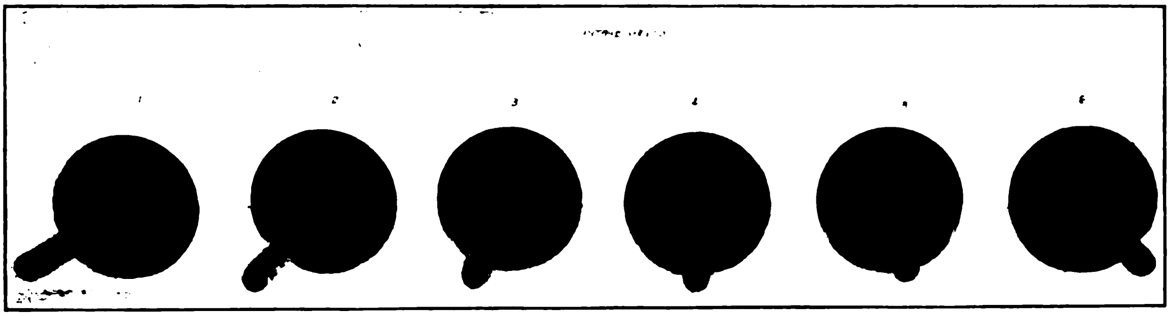


FIG. 10.—Intake valves after 50-hour test. Note the heavy hydrocarbon compound deposits on under side of valves.

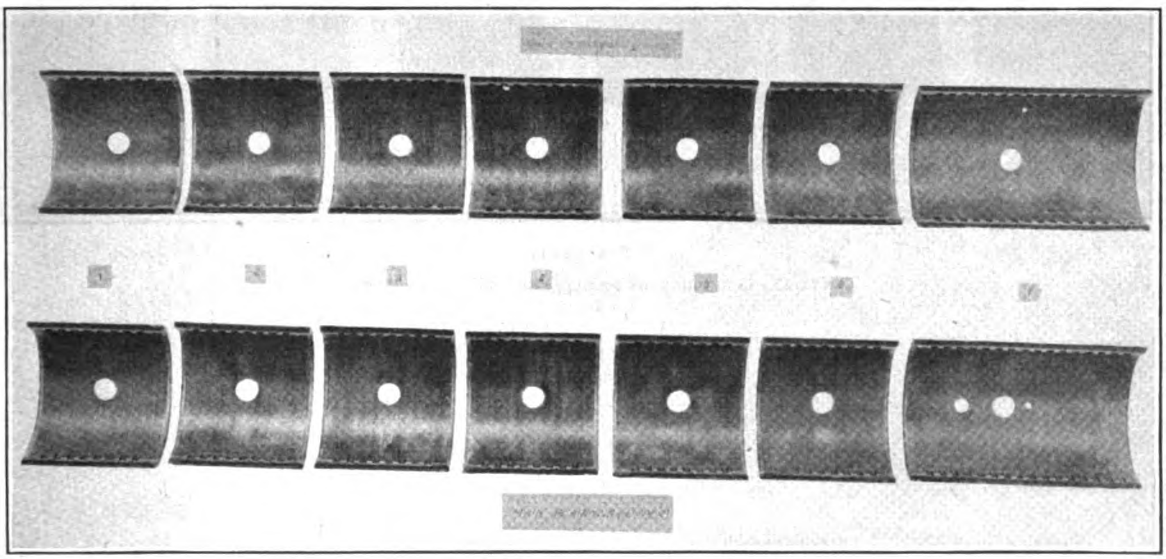
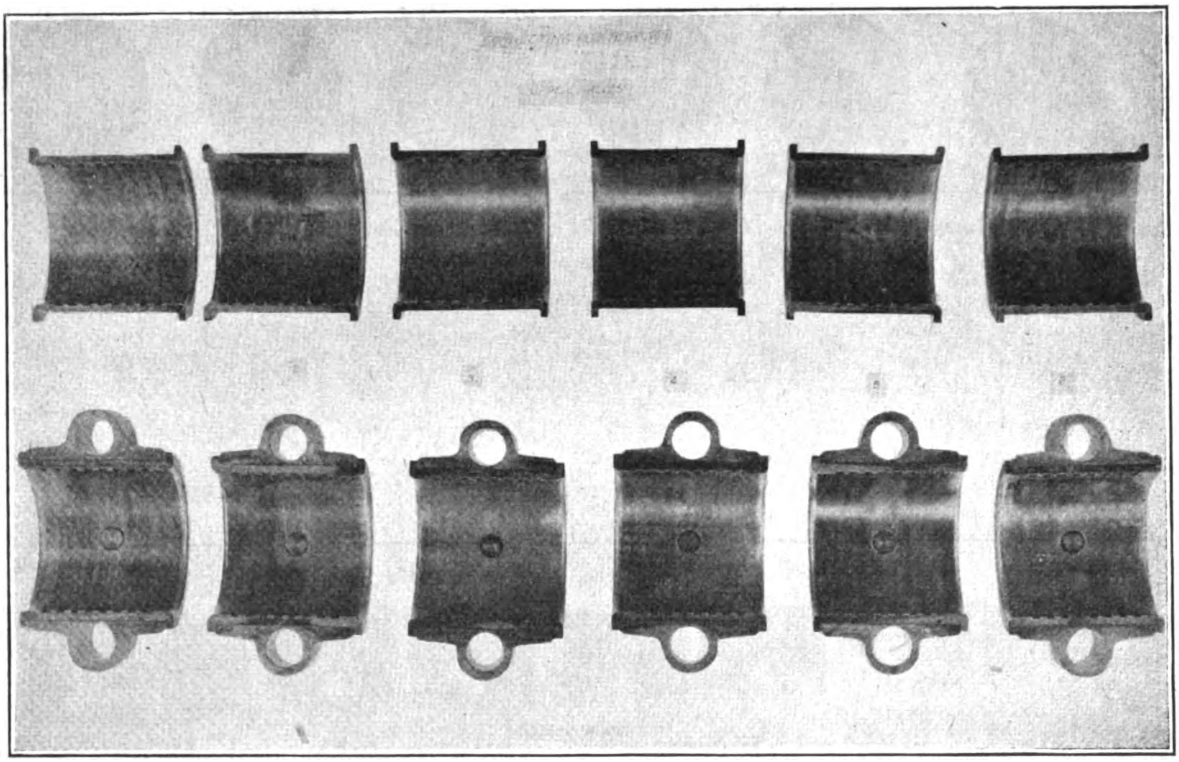


FIG. 11.—Main bearings after 50-hour endurance test.



Lower halves.

FIG. 12.—Connecting rod bearings after 50-hour endurance test.

[redacted] USE ONLY
File D-52.41/Aeromarine/73

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 325

STANDARD ENGINE REPORT OF AEROMARINE MODEL U-8-D AVIATION ENGINE RATED AT 180 HORSE-POWER AT 1,750 REVOLUTIONS PER MINUTE

(POWER PLANT SECTION REPORT)

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
September 14, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INDEX.

STANDARD ENGINE REPORT OF AEROMARINE MODEL U-8-D AVIATION ENGINE RATED AT 180 HORSEPOWER AT 1,750 REVOLUTIONS PER MINUTE.

OBJECT.

The object of this test was to obtain complete information concerning the design and performance of the Aeromarine Model U-8-D Engine.

SUMMARY OF RESULTS.

Normal brake horsepower at full throttle, 191.7 brake horsepower at 1,750 revolutions per minute.

Fuel consumption at normal horsepower, 0.474 pound per (actual) brake horsepower hour.

Oil consumption at normal horsepower, 0.0315 pound per (actual) brake horsepower hour.

Brake mean effective pressure at full throttle, normal speed, 117.6 pounds per square inch.

Total weight, dry, 544.6 pounds.

Weight, dry, per normal brake horsepower, 2.84 pounds.

CONCLUSIONS.

The engine appears to fill the requirements of a moderate powered training engine with regard to design and performance. The design is especially good in respect to ease of overhaul and maintenance. No conclusions are possible as to its reliability and durability until a fifty-hour test has been completed, the results of which will be covered in a separate report.

DESCRIPTION.

Type:
- Name....Aeromarine.
- Model....U-8-D.
- Serial number....1017 (Mnfr's).
- Number and arrangement of cylinders....Eight in two banks of four, 60°V.
- Drive....Direct.
- Cooling....Water.
- Cycle....Four-stroke.
- Fuel....Gasoline.
- Mounting....Either tractor or pusher.
- Cannon adaptation....None.

Manufacturer:
- The Aeromarine Plane & Motor Co., Keyport, N. J.

Characteristic features:
- Cylinder water jackets integral with crank case upper half.
- Removable steel cylinder liners.
- Removable en bloc aluminum cylinder heads with cast-iron valve seats.
- Three-bearing crank shaft.
- Laminated, double-cantilever valve springs operating four valves per cylinder.
- Oil circulation through crank shaft, with positive pressure feed to crank-pin bearings.

Crank case (see figs. 6, 7, 8, and 9):
- Material—
  - Upper half....Aluminum.
  - Lower half....Aluminum.
- Location of parting flange....Slightly below crank-shaft center line.
- Method of clamping....Stud bolts in upper half.
- Number of crank-shaft bearings....Three.

Crank case—Continued.
- Type of bearings....Plain.
- Material....Babbitt-lined bronze.
- Method of support....Bearing caps bolted to upper half.
- Method of securing....Flanged.
- Method of adjusting....None.
- Type of oil grooves....One circumferential groove.
- Engine mounting flanges:
  - Number....Two.
  - Location....Length of crank case, both sides.
  - Type....Integral flanges.
  - Number of bolts in each flange....Eight.
- Upper half—
  - Type of webs....Double, box section.
  - Bearing caps—
    - Material....Steel forgings with Babbitt-lined bronze bushings.
    - Method of retaining....Studs and flanges.
- Breathers—
  - Number....Two.
  - Location....Each end of V.
  - Type....Screened holes.
  - Oil passages....One passage from parting line to central main bearing.
- Lower half:
  - Function....Oil sump and pump support.
  - Type of webs....None.
  - Breathers....None.
  - Compartments....None.
  - Oil passages....Oil pipe from pressure pump to relief valve. Cored passage from relief valve to parting flange. Pipe from strainer to scavenging pump (see fig. 9).

Crank shaft (see fig. 10):
- Type....Integral.
- Material....Forged steel.
- Method of boring....Straight bored throughout.
- Method of counterweighing....None.
- Method of retaining gears....Pump gear by screws—cam shaft drive gear by key and nut.
- Method of retaining thrust bearing....Nut.
- Type of thrust bearing....Double race, radial and thrust ball bearing.
- Thrust-bearing adjustment....Shims.
- Oil passages to shaft....Crank shaft bored throughout. Crank pins and main journals plugged to retain oil. Short tubes projecting into crank pins to separate dirt from oil by centrifugal action.

Propeller hub (see fig. 1):
- Material....Forged steel.
- Type....Removable, 2-piece, with integral rear flange.
- Method of securing....Splines and nut.

Connecting rods (see fig. 11):
- Type....Forked and plain.
- Material....Forged steel.
- Section....Tubular.
- Forked rod—
  - Big end arrangement....Marine bearing box with journal for plain rod big end.
  - Type and material of crank-pin bearing....Split babbitt-lined bronze casting
  - Method of securing bearing....Four bolts.
  - Bearing adjustment....None
  - Small end bearing—
    - Type....Plain.
    - Material....Bronze.
    - Retention....Force fit.
    - Adjustment....None.
- Plain rod—
  - Lower end arrangement....Bearing half forged with rod.
  - Lower end bearing—
    - Type....Plain.
    - Material....Steel on bronze.
    - Retention....Two through bolts.
    - Adjustment....None.
  - Upper end bearing....Same as main rod.

Pistons (see figs. 11 and 20):
- Type....Plain trunk.
- Material....Aluminum.
- Internal ribbing....Two across head from pin bosses parallel to pin.
- Rings—
  - Number....Four.
  - Type....Eccentric, diagonal slot.
  - Material....Cast iron.
  - Number and location....Four above pin.
- Oil scrapers and oil holes....One oil groove below pin. Lower ring beveled for oil scraper. Oil holes directly below lower ring.

Piston pin (see fig. 20):
- Material....Forged steel.
- Method of boring....Straight.
- Method of retaining....Free to float, brass plugs at end to prevent scoring cylinder.
- Oil holes....None.

Cylinders (see figs. 4, 5, and 12):
- General—
  - Type....Steel tubes, open at both ends, fitted into aluminum water jackets. Detachable aluminum heads.
- Method of grouping....Two banks of four, 60° V angle.
- Method of securing....Jackets cast with crankcase upper half. Cylinder barrel snug fit in jacket. Secured by head casting. Barrels are interchangeable.
- Barrel—
  - Material....Steel.
  - Construction....Flanged to fit water jackets.
- Head—
  - Type and construction....Cast aluminum in blocks of four. Detachable, secured by through bolts
  - Material and construction of valve seats....Iron cast into head.
  - Material and construction of valve ports....Cored into head casting.
  - Material of valve guides....Cast iron.
  - Type of valve guides....Removable, pressed into place.

Cylinders—Continued.
- Head—Continued.
  - Cooling....Water through cored passages around valve ports and guides.
  - Location and construction of spark plug bosses....Hollow brass plugs screwed into head just below valve ports.
- Water jacket—
  - Material....Aluminum.
  - Construction....Cast with crank case upper half.
  - Provisions for expansion....Cork packing at bottom of barrel.
  - Location of water connections....Inlet at top of water jacket casting, outlet at side of head casting.
  - Special features....Steel barrel rests in machined seats in water jacket casting. Cork packing at bottom of barrel.

Drives (see fig. 21):
- Pump drives—
  - Type of gears....Spur.
  - Number and location....One on crank shaft, one on pump shaft.
- Camshaft drive—
  - Type of gears....Bevel.
  - Number and location....Nine—One on crank shaft, two on vertical shaft, two each on inclined shafts, one each on cam shafts (at propeller end).

Valves (see fig. 16):
- Number per cylinder....Four.
- Location....Head.
- Type....Tulip type inlet; mushroom type exhaust.
- Material....Steel.
- Method of securing springs....Steel link through valve stem and over spring end.
- Valve springs—
  - Number per cylinder....Two.
  - Type....Double laminated flat-leaf springs — each spring operates one inlet and one exhaust valve.
- Material....Steel.

Valve gear (see fig. 14):
- Cam shafts—
  - Material....Forged steel.
  - Type....Integral cams.
  - Cam form....Uniform acceleration.
  - Method of boring....Straight bored throughout.
- Cam-shaft housing—
  - Material....Aluminum.
  - Construction (see fig. 14)....Lower half cast with head. Upper half cast in two parts. Aluminum cover over housing.
  - Method of securing....Studs in cylinder head.
  - Number, type, and material of cam-shaft bearings....Six plain babbitt-lined bronze bearings.
  - Method of securing bearings....Recesses for housing bolts.
  - Type and location of rocker-arm bearings....Mounted on spindles—four to each block.
  - Oil passages in housing....From bearings to rocker spindles.
- Rocker arms—
  - Material....Steel.
  - Construction....Double tappets, single cam follower.
  - Type of cam follower....Roller.

Valve gear—Continued.
Rocker arms—Continued.
Type of tappet....................Floating, with ball joints, fitted in split nuts.
Adjustment of tappet clearance......Adjustment in split nut at end of rocker.

Valve timing is accomplished by adjustment of the cam shaft bevel gear relative to the cam shaft, by means of a vernier arrangement of the gear retaining screws.

Lubricating system (see fig. 5):
Pressure oil pump—
Number....................One.
Type....................Gear.
Material....................Housing, aluminum; gears, steel.
Scavenging oil pump—
Number....................One.
Type....................Gear.
Materials....................Housing, aluminum; gears, steel.
Strainer—
Number....................One.
Type....................Cylindrical.
Material....................Wire mesh.
Location....................Bottom of sump.
Method of removing....................By plug in crank-case bottom.
Relief valves—
Number....................One.
Type....................Spring loaded poppet.
Location....................Side of sump.
Method of adjusting....................Screw controlling spring tension.
Main pressure circuit—

Oil from the pressure pump is led through tubing to the relief valve. From the relief valve it passes through cored ducts and tubing to the central main bearing. This bearing has a continuous groove which is always in registry with large oil holes in the crank-shaft journal. There it enters the crank-shaft bore and flows in both directions to lubricate main bearings, crank pins, cam shaft, and drive and thrust bearing. The feeding of oil to the crank shaft from a continuous groove makes possible a maintenance of lubricant pressure at the crank pins as great as that at the main bearings. Holes at each end of the shaft directing oil spray to gears and thrust bearing permit a rapid flow of cool oil through the shaft. At each crank pin a small tube projects slightly into the oil passage to prevent foreign matter from passing through to the crank-pin and wrist-pin bearings. Cylinder walls and wrist pins are lubricated by splash from the crank shaft.

Auxiliary circuit—

Oil for the cam shaft leaves the crank-shaft bore at the propeller end and is conducted through a copper tube in the water jacket casting to the rear cam-shaft bearing. At this point it enters the cam-shaft bore and flows the length of the shaft to lubricate bearings and valve gear. Excess oil from the cam-shaft housing drains down the inclined shaft housing at the front, lubricating the gear train. The thrust bearing is lubricated directly from the crank-shaft oil passage. Lubrication is supplied to the water pump by a grease cup. The scavenging pump takes its suction from the bottom of the oil sump through a cylindrical wire-mesh strainer.

Cooling system (see figs. 4 and 5):
Water pump—
Number....................One.
Type....................Centrifugal.
Materials....................Aluminum housing and impeller.
Location....................Rear of crank case.
Type of stuffing box....................Bronze and fiber bushings with sealing grooves cut in pump shaft.
Main circulation system—

The pump takes its suction through a single inlet around the shaft and discharges through double outlets to the tops of the cylinder water jackets. The water entering the cylinder block jacket is distributed evenly throughout the jacket by a perforated tube. Additional admission of water to the jackets is provided by small pipes leading from the pump discharges and entering the lower portion of the jackets at the pump end. From the cylinder jackets the water passes to the heads through cored passages past the cylinder head joint. Outlet flanges are provided at both ends of the head inside the "V."

Auxiliary system—

An auxiliary system to heat the intake manifold takes its water supply from the head jacket of the left block. To facilitate the circulation the outlet from the manifold jacket is led directly to the pump inlet pipe.

Intake manifolds (see fig. 19):
Number....................Two.
Location....................Outside of blocks.
Type....................Unbaffled, straight gallery.
Materials....................Aluminum.
Water jacketing....................None on outer headers.
Type of flanges....................Integral.
Method of removing....................Attached by studs.
Material of gaskets....................Fiber.

NOTE.—An additional carburetor "T" manifold conducts the fuel mixture from the carburetor to cored passages in each head which lead to the outer manifolds. A water jacket is fitted at the top of this manifold.

Carburetors (see fig. 19):
Number....................One.
Name....................Zenith.
Type....................Duplex, automobile type without mixture control.
Manufacturer....................Zenith Carburetor Co., Detroit, Mich.
Materials—
Body....................Aluminum.
Nozzle....................Brass.
Jets....................Brass.
Type of strainer....................Cylindrical wire mesh.
Method of removing strainer....................Held by brass cap.
Main jet system—

Fuel flows from the bottom of the float chamber through the bottom of the idling well to the main jet in the base of the main nozzle. The compensating jet is carried in the base of the idling well and communicates through a small passage with the compensating nozzle surrounding the main nozzle. It receives its fuel from the main fuel passage.

The idling tube carried in the idling well is supplied with fuel by the compensating jet. It communicates with the throat passage just above the throttles. Idling adjustment is accomplished by regulation of variable orifices in the top of the idling tube. The venturi is removable. The throttle is a plain butterfly valve. No mixture control is fitted on the carburetor used in the dynamometer tests.

Ignition:
Name of system....................Dixie.
Type....................Magneto.
Manufacturer....................Splitdorf Electrical Co., Newark, N. J.
Model....................860.
Number of magnetos....................Two.
Number of cylinders and plugs per cylinder fired by each....................One plug each, eight cylinders.
Type of magnetos....................Inductor.
Rotation....................Opposite.
Timing adjustments....................By varying bolt positions in couplings.
Spark advance and retard mechanism....None.

Spark plugs:
Name....................A. C.
Manufacturer....................Champion Ignition Co., Flint, Mich.
Number per cylinder....................Two.
Material of insulator....................Porcelain.
Material of body....................Steel.
Type of gap....................Single; cross bar grounded electroded.
Type of terminal correction....................Ball.

Auxiliaries (see figs. 1, 2, and 3):
Tachometer drives—
Number....................Two.
Location....................Rear end of cam shafts.

Auxiliaries (see figs. 1, 2, and 3)—Continued.
- Starter—
  - Type....Electric, mounted on magneto bracket casting.
  - Manufacturer....Bijur Motor Appliance Co., Hoboken, N. J.

Airplane mounting:
- Type of mounting required....Straight engine bearers.
- Connections and controls—
  - Carburetor controls—
    - Number....Two.
    - Nature....Throttle and altitude control.
    - Location....In V
    - Type....Thrust rods.
  - Tachometer connections—
    - Number....Two.
    - Location....Rear of cam shafts.
  - Cooling-system connections—
    - Inlet—
      - Number....One.
      - Location....Water pump.
    - Outlet—
      - Number....Two.
      - Location....Front or rear of cylinder head castings.
  - Exhaust system—
    - Type of manifolds to be used....Vertical pipes in V
- Connections and controls—
  - Lubrication system connections—
    - Number (dry sump system)—
      - Inlet....One.
      - Outlet....One.
      - Pressure gage....One.
      - Location....Rear end of crank case.
  - Fuel-system connections—
    - Number....One.
    - Location....In V
  - Ignition-system connections—
    - Number....Two, ground wires.
    - Location....Magneto breaker boxes.
  - Starter connections—
    - Number....One, cable from starting switch to starting motor.

METHOD OF TEST.

The engine was connected to an electric cradle dynamometer and the following runs made:

- 2 full-power runs.
- 2 propeller load runs.
- 1 friction horsepower run.
- 1 one-hour fuel and oil consumption run.
- 1 oil pump capacity run.
- 1 water pump capacity run.

Readings were made in accordance with standard methods completely described in Engineering Division Report, Serial No. 1507.

RESULTS OF TESTS.

The results of the tests are given concisely in the tables, pages 8–10, and curves, pages 22–26. It should be remembered that the laboratory conditions of test are much more favorable to satisfactory performance than are those of actual flight so that these results may be assumed to be slightly better than the normal operating performance of the engine. Since no reliable method has yet been proposed for applying corrections to errors resulting from air temperature variations, no such corrections have been made. The air temperature on test, however, was very near to the standard temperature of 60° F., and the error due to this cause is probably negligible.

OBSERVATIONS ON TEST.

The engine operation was very satisfactory. Two slight water leaks through the cylinder water jacket casting at the outer side of the left bank (center) and at the oil tube to the valve gear (left bank) were discovered during the one hour consumption run. No oil leakage was noted. The engine in the matter of smoothness compares favorably with service engines of similar construction and power.

TEAR-DOWN INSPECTION.

At the completion of the runs listed the engine was disassembled for inspection. All parts were found to be in excellent condition. The principal bearing surfaces were only slightly scratched and barely perceptible wear was noted on gears.

ANALYSIS OF ENGINE.

DESIGN.

Valve gear.—The valve gear with laminated flat springs appears to operate satisfactorily. Its chief advantage lies in the ease with which springs can be removed.

Cylinder head casting.—The extremely small cooling water passages in the head seem likely to prove troublesome, due to accumulation of sediment, when very hard or otherwise impure water is used for cooling. The removable head greatly simplifies the matter of top overhaul.

Connecting rods.—The small clearance afforded in the forked end of the main rod makes it necessary to remove the bronze box from this rod before the plain rod big end can be dismantled.

Adaptability to production.—No particularly difficult or expensive manufacturing processes are apparent in the engine construction. Cylinder, crank-case halves, and jackets are very simple. The connecting rods are of marine straddle type and therefore easily constructed. The head castings alone present any considerable difficulties, the foundry work being rather complex due to the nature of the ports and water passages.

PERFORMANCE ON TEST.

A comparison of the performance of this engine with that of the Hispano-Suiza model "E" follows:

	Hispano-Suiza model "E."	Aeromarine U-8-D
Brake horsepower at 1,800 revolutions per minute	189.9	199.5
Specific fuel consumption, pounds per horsepower per hour at 1,800 revolutions per minute	.493	.467
Oil consumption, pounds per horsepower per hour (normal speed)	.0193	.0315
Brake horsepower at 1,800 revolutions per minute per cubic inch piston displacement	.264	.270
Weight, pounds per brake horsepower	2.510	2.722
Brake mean effective pressure pounds per horsepower at 1,800 revolutions per minute	116.20	118.80

ADAPTABILITY TO AIRPLANE.

The engine is of clean design, easily mounted and easily streamlined. Its head resistance, 3.5 square feet, is rather low.

ACCESSIBILITY.

The spark plugs and carburetor are easily accessible with the engine mounted. Valve adjustments necessitate the removal of the head covers. The magnetos at the

rear of the engine face with distributors outward and so are readily reached through the cowling. The oil strainer is secured by cap screws in the bottom of the crank case and may readily be withdrawn for cleaning. The oil pressure relief valve is located at the side of the crank case just below the parting flange, and is, therefore, accessible. Water pump removal requires the removal of the magneto and starter gear housing.

SERVICE.

The engine is easily overhauled. Top overhaul is particularly simple, due to the removable heads and flat valve springs. In maintaining this engine in the field, cylinder heads requiring valve grinding or other repairs could be replaced by heads in good condition in a very short time and without removing the engine from the airplane. Complete overhaul is simplified by the removable heads, the clean crank-case design, and the simplicity of the drive layout. The removable heads, however, seem likely to give trouble in maintaining a tight gasket surface between cylinders and heads, particularly at the water jacket joints. Some leakage there has already been noted on further tests of the engine.

For service use this engine should be fitted with a carburetor with altitude control. The jet setting also will probably require enriching for satisfactory service operation.

AEROMARINE ENGINE WEIGHTS.

		Pounds.	Per cent.
Crank-case group:			
Upper half with water jackets, cylinder barrels, bearings, etc	147.5		
Lower half with oil filter and relief valve	20.2		
Total		167.7	30.8
Crank-shaft group:			
Crank shaft with gears, thrust bearing, etc		65.4	12.0
Propeller hub assembly, complete		9.9	1.8
Connecting-rod group:			
4 connecting-rod assemblies averaging 7.4 pounds each		29.6	5.4
Piston group:			
8 piston assemblies, complete, with rings averaging 2.56 pounds each		20.5	3.8
Cylinder-head group:			
2 head castings, including bearings, valves, rocker levers, springs, etc	119.6		
2 head covers	19.5		
Total		139.1	25.5
Driving-gear group:			
Vertical shafts and gears	4.8		
Inclined shafts and gears	4.2		
Starter gear and magneto drive assembly	11.4		
Total		20.4	3.8
Lubrication group:			
1 oil pump assembly, complete		5.3	1.0
Cooling-system group:			
1 water pump assembly	3.6		
Water manifolds and piping	8.8		
Total		12.4	2.3
Carburetor and intake group:			
1 carburetor assembly	5.4		
1 intake T manifold	5.1		
2 intake headers	8.2		
Total		18.7	3.4
Ignition group:			
2 magneto assemblies	42.9		
16 spark plugs	2.7		
Distributor covers and wires	7.7		
Total		53.3	9.8
Miscellaneous nuts, bolts, washers, etc		2.3	.4
Engine, total		544.6	100.0
Weight of water in engine		47	....

POWER PLANT WEIGHT.

1. Engine weight, dry .... pounds.. 544.6
2. Power plant constant weight: Pounds.
   - (a) Oil radiator and piping 10.0
   - (b) Air intake pipes 3.8
   - (c) Hand starting magneto 8.0
   - (d) Exhaust stacks 8.0
   - (e) Fuel system 50.0
   - (f) Engine controls 8.0
   - (g) Instruments 8.0

   Total .... pounds.. 95.8
3. Cooling system .... do.... 124.7
4. Fuel, oil and tankage:
   - (a) Fuel—
     - Pounds per hour at sea level 91.0
     - Pounds per hour at 10,000 feet 68.1
     - Pounds per hour at 15,000 feet 61.1
   - (b) Oil—
     - Pounds per hour 6.04
     - 3 gallon reserve 22.0
   - (c) Fuel tanks—
     - Gravity tank .... pounds.. 18.2
     - Leak-proof tank per pound fuel .... do.... .345
   - (d) Oil tanks—
     - Per pound oil .... do.... .267

POWER PLANT WEIGHT (POUNDS) BY CLASS OF SERVICE.

	Pursuit.[1]	Two-place.[2]	Bombing.[3]	Training.[4]	Long-distance cruising.[5]
Engine weight, dry	544.6	544.6	544.6	544.6	544.6
Power plant constant weight	95.8	95.8	95.8	95.8	95.8
Cooling system	124.7	124.7	124.7	124.7	124.7
Tankage	97.3	141.0	166.1	195.8	543.2
Fuel	198.3	317.9	386.0	227.5	1,407.5
Oil	40.1	49.2	55.2	37.1	145.9
Total	1,100.8	1,273.2	1,372.4	1,225.5	2,861.7
Per horsepower	5.74	6.64	7.16	6.39	14.92

[1] ½ hour at sea level, 2½ hours at 15,000 feet.
[2] ½ hour at sea level, 4 hours at 10,000 feet.
[3] ½ hour at sea level, 5 hours at 10,000 feet.
[4] 2½ hours at sea level.
[5] ½ hour at sea level, 20 hours at 10,000 feet.

DIMENSIONS.

General:
- Bore .... inches.. 4.25.
- Stroke .... do.... 6.50.
- Compression ratio .... 5.38:1.
- Rotation of propeller (facing propeller) ... Counterclockwise.
- Total piston displacement.. cubic inches.. 738.0.
- Approximate head resistance. square feet.. 3.5.
- Firing order .... 1L–4R–3L–2R–4L–1R–2L–3R.
- Method of numbering cylinders .... (See fig. 3.)

Crank case:
- Distance between cylinder center—
  - 1–2 and 3–4 .... inches.. 4.75.
  - 2–3 .... do.... 8.00.
- Diameter main bearing studs ...... inch.. 0.50.
- Main crank-shaft bearings—

No.	Diameter.	Length.	Diametral clearance.	End clearance.	Projected area.
	Inches.	*Inches.*	*Inch.*	*Inch.*	*Square inches.*
1	2.506	2.500	0.006	0.05	6.265
2	2.505	3.062	.005	.188	7.680
3	2.506	2.500	.006	....	6.265

Engine hold-down bolts: Number 16, diameter, 0.4375 inch.
Crank shaft:

No.	Outside diameter.	Length.	Diameter bore.
Main journals:	*Inches.*	*Inches.*	*Inches.*
1	2.500	2.550	1.750
2	2.500	3.250	2.000
3	2.500	3.563	2.000
Crank pins:			
1	2.500	2.510	1.750
2	2.500	2.510	1.750
3	2.500	2.510	1.750
4	2.500	2.510	1.750

Crank cheeks:
Width— Inches.
1, 3, 4, and 6 ... 3.500
2 and 5 ... 3.000
Thickness—
1, 3, 4, and 6 ... 1.000
2 and 5 ... 2.000
Length of shaft, front end to first crank cheek ... 16.625
Thrust bearing:
Manufacturer and number ... Hess Bright, No. 8312.
Propeller hub mounting (see fig. 1):
Two removable cones with splines on crank shaft and hub.
Length of bearing surface of cones, parallel to shaft—
Rear ... inch .. 0.3125.
Front ... do ... 0.750.
Diameter—
Front cone ... inches .. 2.125 x 2.893.
Rear cone ... do ... 2.4375 x 2.740.
Propeller hub:
Diameter hub body ... inches .. 2.500.
Length between flanges ... do ... 5.00–5.50.
Diameter bolt circle ... do ... 6.000.
Number of bolts ... 8.
Diameter of bolts ... inch .. 0.440.
Connecting rods:
Length of plain rod, center to center ... inches .. 12.00.
Number of bolts ... 2.
Minimum diameter of shank ... inch .. 0.4375.
Threads, per inch ... 20.
Length of forked rod, center to center ... inches .. 12.00.
Number of bolts ... 4.
Minimum diameter of shank ... inch .. 0.375.
Threads, per inch ... 24.
Rod-stroke ratio ... 1.846 : 1.
Wrist-pin bushing:
Length ... inches .. 1.750.
Diameter ... do ... 1.128.
Projected area ... square inches .. 1.975.
End play of rod on pin ... inch .. 0.125.
Big end bearing, plain rod:
Length ... inches .. 1.250.
Diameter ... do ... 2.875.
Diametral clearance on forked rod ... inch .. 0.008.
End clearance in forked rod ... do ... 0.018.
Big end bearing, forked rod:
Length ... inches .. 2.495.
Clearance on crank pin—
Diametral ... inch .. 0.005.
End ... do ... 0.005.
Projected area on crank pin .. square inches .. 6.24.
Pistons:
Area of head ... do ... 14.08.
Distance, center of pin to top of piston ... inches .. 2.000.
Length over all ... do ... 3.750.
Length of bearing in cylinder ... do ... 3.250.
Clearance in cylinder—
Top ... inch .. 0.017.
Botton ... do ... 0.010.
Rings:
Number per piston ... 4.
Tension ... pounds .. 5.25.
Width ... inch .. 0.125.
Width of gap, ring in cylinder ... do ... 0.035.
Pin:
Length—
Ground surface ... inches .. 3.9375.
Over-all ... do ... 4.190.
Diameter ... do ... 1.118.
Diameter, bore ... inch .. 0.571.
Total length of bearing in piston ... inches .. 2.0625.

Cylinders:
Bore ... inches .. 4.250.
Stroke ... do ... 6.500.
Stroke-bore ratio ... 1.529 : 1.
Piston displacement of engine ... cubic inches .. 738.0.
Piston displacement of cylinder ... do ... 92.25.
Compression volume of cylinder ... do ... 21.06.
Compression ratio ... 5.38 : 1.
Per cent compression ... 18.58.
Port openings: Intake. Exhaust.
Number per cylinder ... 2 2
Diameter ... inches .. 1.750 1.625
Water connections: Inlet. Outlet.
Number ... 4 4
Inside diameter ... inches .. 0.500 and 1.4375 1.000
Minimum thickness of water space around cylinder barrel ... inch .. 0.250.
Cylinder-head hold-down studs: Number, 24—12 in each head; diameter, 0.4375 inch; threads per inch, 20.

Drive gears:

Gear.	Type.	Pitch diameter.	Number of teeth.	Face width at pitch line.	Minimum diameter of shaft.
		Inches.		*Inch.*	*Inches.*
C. S. auxiliary drive	Bevel.	4.125	33	0.500	2.9375
Vertical shaft—					
Lower	..do..	2.750	22	.55	.131
Upper	..do..	2.750	22	.45	.131
Inclined shaft—					
Lower	..do..	2.750	22	.45	.797
Upper	..do..	1.625	13	.500	1.00
Cam-shaft gear	..do..	4.875	39	.500	1.092
Crank-shaft pump gear	Spur..	4.500	45	.250	2.500
Pump gear	..do..	4.000	40	.250	
Magneto drive gear	Hel...	2.307	15		
Magneto shaft gear	..do..	2.307	15		

Cam shaft:
Outside diameter ... inches .. 1.25
Bore diameter ... inch .. .625

Journals—

Number.	Diameter.	Length.
	Inches.	*Inches.*
1	1.250	2.500
2	1.250	2.625
3	1.250	1.6875

Bearings—

Number.	Length.
	Inches.
1	2.250
2	2.500
3	1.625

Cams—

	Body, diameter.	Width.	Lift.
	Inches.	*Inch.*	*Inch.*
Intake	1.250	0.3125	0.288
Exhaust	1.250	.3125	.288

Rocker arms— Inches.
Length valve lever ... 1.375
Length cam lever ... .875
Diameter spindle ... .500

Valves:

	Inlet.	Exhaust.
Number per cylinder	2	2
Outside diameter....inches..	1.8375	1.780
Inside diameter....do....	1.700	1.575
Lift....inch..	.4375	.4375
Angle of seat	30°	30°
Angle of stem with cylinder axis	25°	25°
Total area of opening, square inches both valves.	2.25	2.10
Stem diameter....inch..	.343	.405
Tappet, clearance....do....	.013	.013

Valve springs—
Number per cylinder ..... ½
Tension inlet—
Valve open ..... pounds.. 45
Valve closed ..... do.... 30
Tension exhaust—
Valve open ..... do.... 45
Valve closed ..... do.... 30

Valve timing—

	Designed.	Actual (average).
Inlet—		
Opens	10° ATC	11.4° ATC.
Closes	42° ABC	41.9° ABC.
Exhaust—		
Opens	45° BBC	47.4° BBC.
Closes	10° ATC	7.6° ATC.

Oil pump:

	Pressure.	Scavenging.
Number and type	1	1.
Material—		
Casing	Aluminum..	Aluminum.
Gears	Steel	Steel.
Speed	9/8 C. S.	9/8 C. S.
Number of gears	2	2.
Pitch diameter of gears....inches..	1.625	1.625.
Number of teeth	8	8
Face width....inch..	0.6875	1.625.

Oil connections from engine to tank—
Inside diameter— Inches.
Inlet 0.594
Outlet ..... .750

Water pump:
Material—
Housing ..... Aluminum.
Rotor ..... Aluminum.
Type ..... Centrifugal.
Speed ..... 9/8 C. S.
Diameter, rotor ..... inches.. 4.00
Number of vanes 6
Width of vanes at tip ..... inch.. .875
Number of inlets, inside diameter ..... inches.. 1-1.25
Number of outlets, inside diameter ..... do.... 2-1.25
Diameter of shaft ..... inch.. .5625

Water connections to engine:

	Number.	Inside diameter.	Outside diameter.
		Inches.	*Inch.*
Inlet	2	0.500	0.5625
Outlet	2	1.4375	....
	2	1.00	....

Carburetor:
Number ..... 1.
Material, body ..... Aluminum.
Diameter at flange, inside ..... inches.. 1.875.
Choke diameter ..... do.... 1.250.
Metering jets, material ..... Brass.
Diameter—
Main ..... mm.. 1.50.
Compensating ..... do.... 1.60.

Ignition:
Number of magnetos ..... 2.
Speed rotor ..... Crank shaft.
Speed distributor ..... 1/2 C. S.
Width of breaker gap ..... inch.. 0.021.

Spark plugs:
Size of thread ..... Metric (S. A. E. std.).
Gap ..... inch.. 0.018.

Auxiliaries:
Tachometer drive connection—
Speed ..... 1/2 C. S.
Outside diameter threads ..... inch.. 0.875.
Pitch of threads ..... per inch.. 18.

Reciprocating and centrifugal weights:

	Pounds.
Piston, complete with rings and pin	2.51
Upper end of forked connecting rod	1.20
Upper end of plain connecting rod	1.00
Lower end of forked connecting rod	3.29
Lower end of plain connecting rod	1.90
Connecting rod total weights—	
Forked	4.49
Plain	2.90
Total	7.39
Valve, without spring	.25
Weight of spring assembly, for two valves	.50

ENGINE EFFICIENCY TABLE.

Cubic inches piston displacement per brake horsepower at normal speed (1,600 revolutions per minute)	3.850
Brake horsepower per cubic inch piston displacement at normal speed	.2597
Brake horsepower per cubic foot of piston displacement at normal speed	449.0
Brake horsepower per square foot of piston area at normal speed.	217.0
Indicated mean effective pressure at normal speed..lb./sq. in..	136.2
Friction mean effective pressure at normal speed....do....	18.58
Brake thermal efficiency at normal speed....per cent..	28.3
Indicated thermal efficiency at normal speed....do....	32.4
Air standard efficiency....do....	49.67
Efficiency ratio (indicated)	.6525
Efficiency ratio based on brake thermal efficiency	.5700
Mechanical efficiency....per cent..	86.4

FULL POWER RUNS.

FIRST RUN.

R. p. m.	Actual— Brake load lb.	B. hp.	Corrected— Torque, lb.-ft.	Hp.	B. m. e. p., lb. per sq. in.	Water. Temp. ° F. In.	Out.	Oil. Temp. ° F. In.	Out.	Press. lb. per sq. in.	Carb. air temp. ° F.	Man. vac. in Hg.	Carb. vac. in Hg.	Gas. cons. Sec. for 3 lb.	Lb. hp.-hr.	Lb. per hr.
1,249	348.0	144.9	621.7	147.8	126.9	125	142	120	124	38	56	0.9	1.0	138.0	0.540	78.3
1,357	354.0	160.1	632.2	163.3	129.2	121	138	116	126	42	56	1.2	1.1	135.6	.498	79.7
1,458	354.0	172.0	632.2	175.5	129.2	120	144	146	144	38	56	1.4	1.2	131.8	.476	81.9
1,560	344.0	178.8	614.2	182.4	125.5	127	141	132	138	45	56	1.4	1.2	127.5	.473	84.7
1,667	334.5	185.8	597.2	189.6	122.1	126	140	142	142	43	56	1.5	1.3	123.5	.470	87.5
1,760	327.5	192.1	584.7	196.0	119.5	125	139	143	145	46	56	1.6	1.4	119.2	.471	90.6
1,878	320.0	200.3	571.5	204.4	116.8	128	142	144	147	47	57	1.7	1.5	116.5	.463	92.7
1,979	309.5	204.2	552.5	208.3	112.9	126	141	145	148	49	58	1.9	1.6	111.0	.476	97.3
2,082	294.5	204.4	526.0	208.6	107.5	124	139	145	150	49	58	2.2	1.9	105.3	.502	102.6

Average barometer, 29.32 in. Hg.

SECOND RUN.

R. p. m.	Actual— Brake load lb.	B. hp.	Corrected— Torque, lb.-ft.	Hp.	B. m. e. p., lb. per sq. in.	Water. Temp. ° F. In.	Out.	Oil. Temp. ° F. In.	Out.	Press. lb. per sq. in.	Carb. air temp. ° F.	Man. vac. in Hg.	Carb. vac. in Hg.	Gas. cons. Sec. for 3 lb.	Lb. hp.-hr.	Lb. per hr.
1,259	350.0	146.9	624.6	149.8	127.7	124	142	134	136	32	58	0.9	1.0	144.5	0.509	74.7
1,354	357.5	161.4	638.5	164.6	130.4	125	141	153	160	32	58	1.2	1.1	136.5	.490	79.1
1,463	354.0	172.6	631.6	176.0	129.1	124	140	155	158	33	58	1.4	1.2	129.8	.482	83.2
1,558	349.0	181.2	623.0	184.7	127.2	125	140	156	156	35	58	1.5	1.2	111.4	.535	96.9
1,662	337.0	186.7	601.7	190.4	122.8	126	141	154	155	39	59	1.5	1.3	122.5	.472	88.2
1,765	328.0	193.0	585.5	196.8	119.6	127	140	153	153	41	59	1.6	1.4	119.5	.468	90.4
1,865	319.5	198.6	570.0	202.5	116.5	128	141	151	151	42	59	1.7	1.5	113.0	.481	95.6
1,965	309.0	202.4	552.4	206.4	112.8	127	141	150	151	45	59	1.9	1.6	110.8	.481	97.5
2,077	296.0	204.9	528.3	209.0	107.9	124	141	150	151	47	59	2.1	1.8	104.7	.503	103.2

Average barometer, 29.32 in. Hg.

PROPELLER LOAD RUNS.

FIRST RUN.

R. p. m.	Actual— Brake load lb.	B. hp.	Corrected— Torque, lb.-ft.	Hp.	Water. Temp. ° F. In.	Out.	Oil. Temp. ° F. In.	Out.	Press. lb. per sq. in.	Carb. air temp. ° F.	Man. vac. in. Hg.	Carb. vac. in. Hg.	Gas. cons. Sec. for 3 lb.	Lb. hp.-hr.	Lb. per hr.
1,766	327.0	192.5	584.0	196.4	130	143	152	150	42	60	1.6	1.4	120.4	0.466	89.7
1,666	289.5	160.8	517.2	164.1	123	137	150	150	41	60	2.9	1.0	142.0	.473	76.1
1,554	256.5	132.9	458.2	135.6	125	138	148	148	41	60	5.7	.6	164.3	.494	65.7
1,449	225.0	108.7	402.0	110.9	129	141	145	145	40	60	8.0	.5	195.0	.509	55.4
1,340	194.0	86.7	346.4	88.5	124	138	143	144	39	60	10.2	.4	238.0	.524	45.4
1,243	166.5	69.0	297.2	70.4	129	140	142	144	37	60	11.9	.3	245.0	.639	44.1

Average barometer, 29.32 in. Hg.

SECOND RUN.

R. p. m.	Actual— Brake load lb.	B. hp.	Corrected— Torque, lb.-ft.	Hp.	Water. Temp. ° F. In.	Out.	Oil. Temp. ° F. In.	Out.	Press. lb. per sq. in.	Carb. air temp. ° F.	Man. vac. in. Hg.	Carb. vac. in. Hg.	Gas. cons. Sec. for 3 lb.	Lb. hp.-hr.	Lb. per hr.
1,778	327.0	193.8	584.0	197.8	129	142	147	150	44	60	1.6	1.4	119.0	0.468	90.8
1,658	289.0	159.7	516.0	162.9	120	134	150	150	42	60	2.9	1.0	134.6	.502	80.3
1,547	256.0	132.0	457.1	134.7	124	137	136	140	41	60	5.6	.7	162.7	.503	66.4
1,444	224.0	107.9	400.0	110.1	128	140	122	130	42	61	8.0	.5	189.5	.528	57.0
1,347	194.0	87.2	346.4	89.0	126	139	106	116	44	61	10.1	.4	198.6	.624	54.4
1,248	167.0	69.5	298.2	70.9	125	137	125	126	37	61	12.0	.3	249.4	.623	43.3

Average barometer, 29.32 in. Hg.

FRICTION HORSEPOWER RUN.

Tachometer, r. p. m.	Corrected engine, b. hp. (from curve).	Friction load, lb.	Friction, hp.	F. m.e. p., lb. per sq. in.	Per cent, mech. eff.	Water. Temp., °F.		Oil. Temp., °F.	
						In.	Out.	In.	Out.
1,250	148.0	41	17.1	14.7	89.7	142	143	112	120
1,350	163.0	43	19.4	15.4	89.4	139	140	116	121
1,450	174.5	44	21.3	15.8	89.1	139	140	129	128
1,550	183.0	44	22.7	15.7	89.0	140	141	133	134
1,650	190.0	48	26.4	17.2	87.8	140	142	143	142
1,750	196.0	52	30.3	18.6	86.6	138	140	156	152
1,850	201.0	64	39.5	22.9	83.6	139	140	155	155
1,950	205.0	67	43.6	24.0	82.5	140	142	151	153
2,050	208.2	65	44.4	23.2	82.5	142	144	147	153

Length of brake arm, 21 inches; kind of oil used, United States Spec. No. 3501; average barometer, 29.32 in. Hg.; average carburetor air temperature, 60 °F.

ONE HOUR FUEL AND OIL CONSUMPTION RUN.

Time, min.	R. p. m.	Actual—		Corrected—		Water.		Oil.			Carb. air temp., °F.	Man. vac. in. Hg.	Carb. vac. in. Hg.	Gas cons.		Oil cons.	
		Brake load, lb.	B. hp.	Hp.	B. m. e. p., lb. per sq. in.	Temp., °F.		Temp., °F.		Press., lb. per sq. in.				Scale reading, lb.	Lb. hp.-hr.	Scale reading, lb.	Lb. hp.-hr.
						In.	Out.	In.	Out.								
0	1,778	317	187.9	191.7	115.7	127	140	108	122	60	64	1.6	1.4	124.0	....	13.0	....
5	1,768	316	186.3	190.0	115.3	127	142	126	139	61	64	1.6	1.4	116.6	0.475	13.1	....
10	1,774	322	190.4	194.4	117.6	126	140	120	136	61	64	1.6	1.4	108.8	.492	12.4	....
15	1,765	323	190.0	193.9	117.8	128	142	140	149	61	62	1.6	1.4	101.3	.473	12.5	....
20	1,781	323	191.7	195.5	117.8	124	139	134	146	61	62	1.6	1.4	93.8	.472	11.4	....
25	1,776	322	190.6	194.5	117.5	126	140	129	140	61	62	1.6	1.4	86.4	.465	12.0	....
30	1,775	325	192.3	196.2	118.6	128	141	159	158	61	61	1.6	1.4	78.9	.470	11.4	....
35	1,772	325	192.0	195.9	118.6	125	139	151	156	61	61	1.6	1.4	71.5	.462	10.3	....
40	1,780	324	192.2	196.1	118.3	124	138	150	154	61	61	1.6	1.4	64.0	.468	9.2	....
45	1,765	324	190.6	194.5	118.2	125	139	149	153	61	60	1.6	1.4	56.4	.476	8.6	....
50	1,769	323	190.5	194.4	117.9	129	142	148	151	61	60	1.6	1.4	48.9	.473	8.1	....
55	1,769	323	190.5	194.4	117.9	125	139	147	151	61	60	1.6	1.4	41.3	.479	7.3	....
60	1,765	322	189.5	193.3	117.5	125	138	146	150	61	60	1.6	1.4	33.8	.474	7.0	....
AVERAGE RESULTS FOR 1 HOUR.																	
1	1,772	322.2	190.3	194.2	117.6	126.1	139.9	139.0	146.5	61	61.6	1.6	1.4	[1] 90.2	0.474	[1] 6.0	0.0315

[1] Total for 1 hour.

Average barometer, 29.32 in. Hg.
Data for all runs: Length of brake arm, 21 inches; kind of oil used, United States Spec. No. 3501; specific gravity gasoline, 0.703 at 60 °F.

OIL PUMP CAPACITY RUN – PUMPING THROUGH ENGINE.

R. p. m.	Water. Temp., °F.		Oil. Temp., °F.		Oil. Press., lb. per sq. in.	Oil flow. Lb.	Oil flow. Sec.	Oil flow, lb. per hr.
	In.	Out.	In.	Out.				
1,229	136	138	138	139	60	5	11.4	1,579
1,501	137	139	134	138	61	5	10.0	1,800
1,654	139	140	136	140	61	5	9.4	1,915
1,877	140	142	136	141	62	5	8.7	2,069
2,049	140	143	138	144	63	5	8.2	2,195

OIL PUMP CAPACITY RUN—FREE OUTLET.

Engine, r. p. m.	Pump, r. p. m.	Torque, lb. ft.	Horse-power.	Capacity, lb. per hour.	Temperature, °F.
PRESSURE PUMP.					
1,250	1,406	1.7	0.46	2,140	100
1,450	1,630	1.9	.59	2,430	....
1,650	1,850	2.1	.74	2,610	104
1,850	2,080	2.2	.87	2,950	....
2,050	2,305	2.5	1.10	3,050	110
SCAVENGE PUMP.					
1,250	1,406	2.2	0.59	5,000	90
1,450	1,630	2.4	.75	5,450	....
1,650	1,850	2.7	.95	5,810	94
1,850	2,080	2.9	1.15	6,920	102
2,050	2,305	3.0	1.32	7,500	110

Oil specific gravity, 0.870.

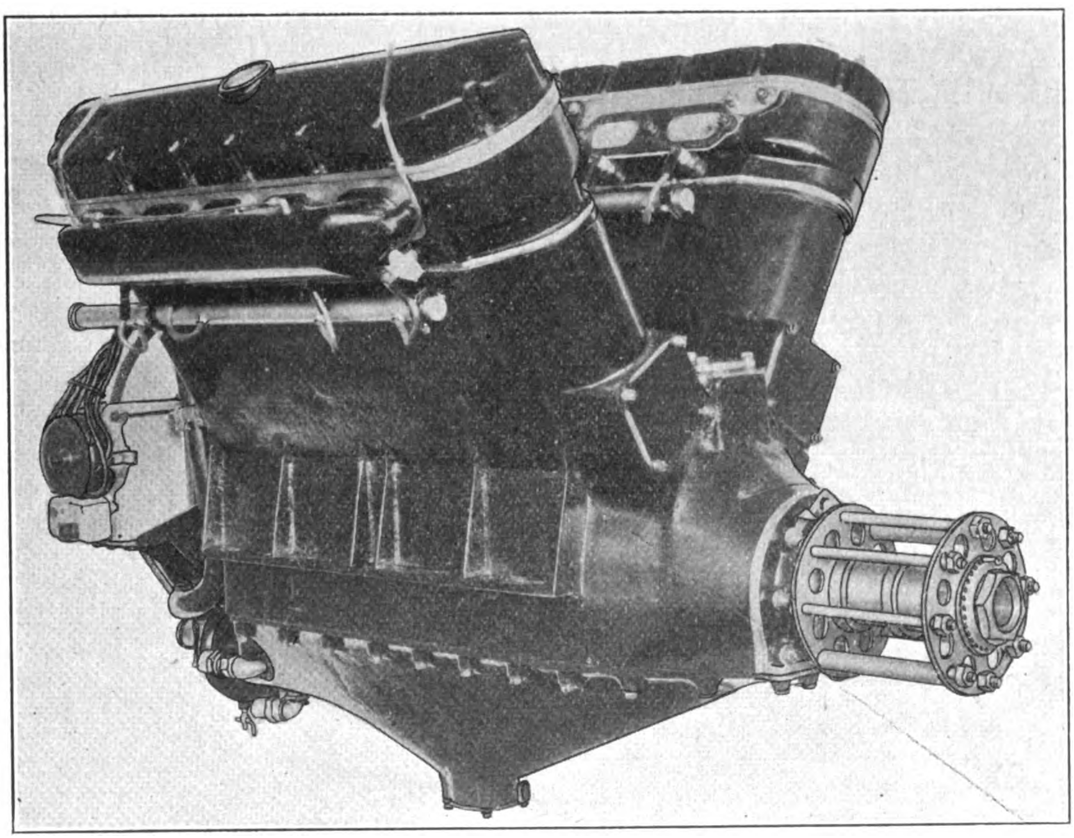


FIG. 1.—Three-quarter front view.

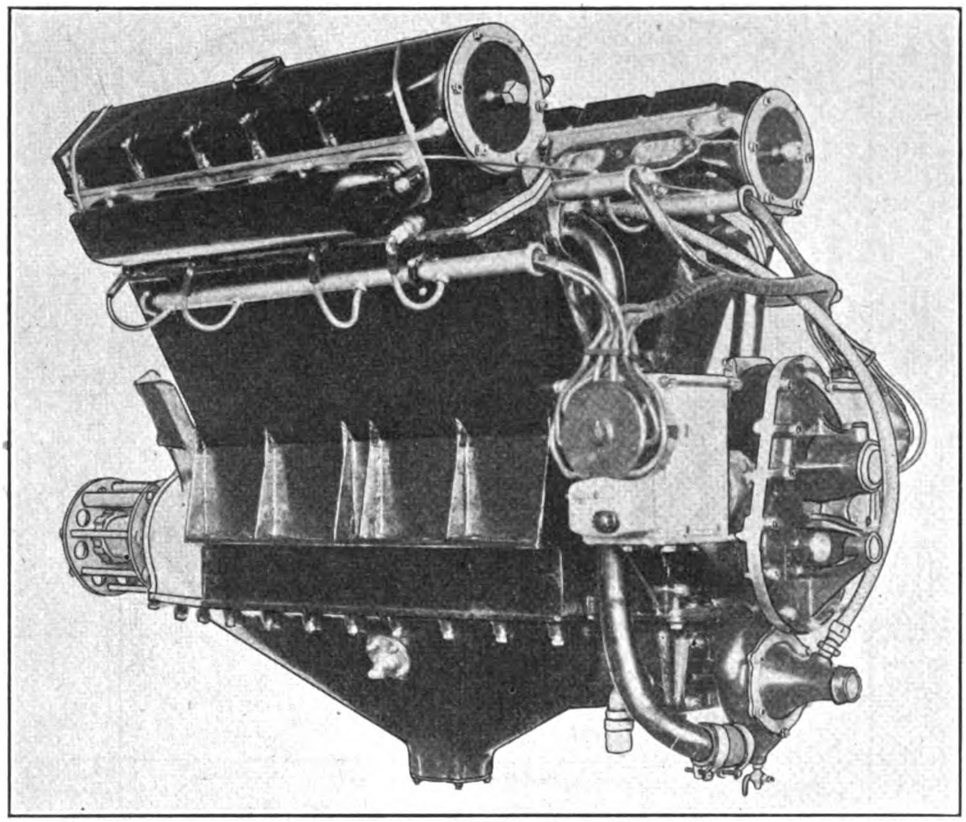


FIG. 2.—Three-quarter rear view.

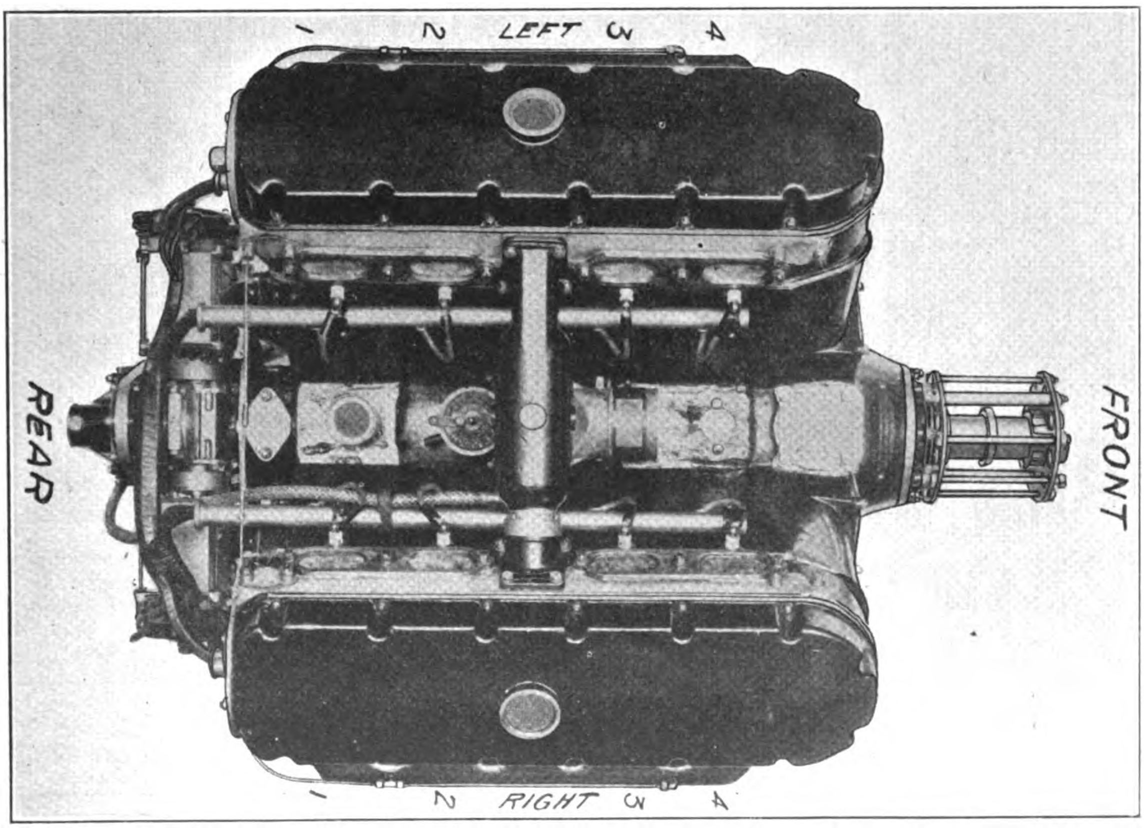


FIG. 3.—Top view.

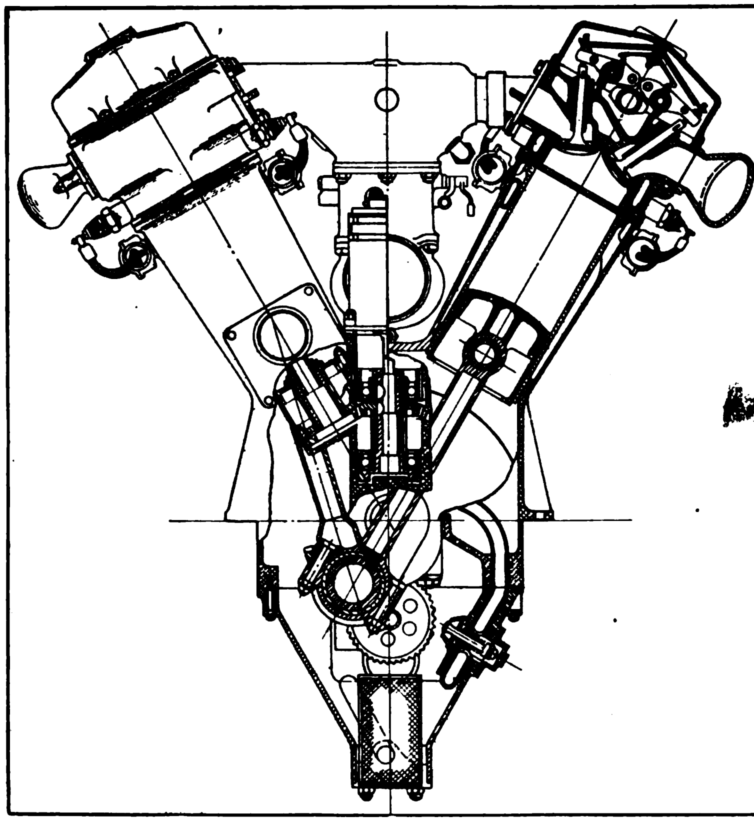


FIG. 4.—Vertical section.

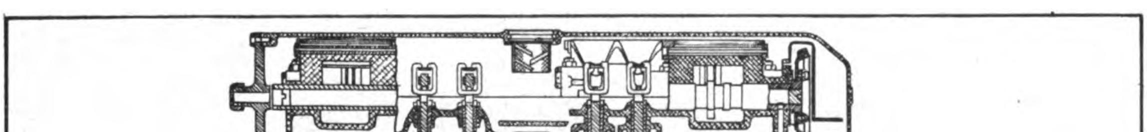


FIG. 5.—Longitudinal section.

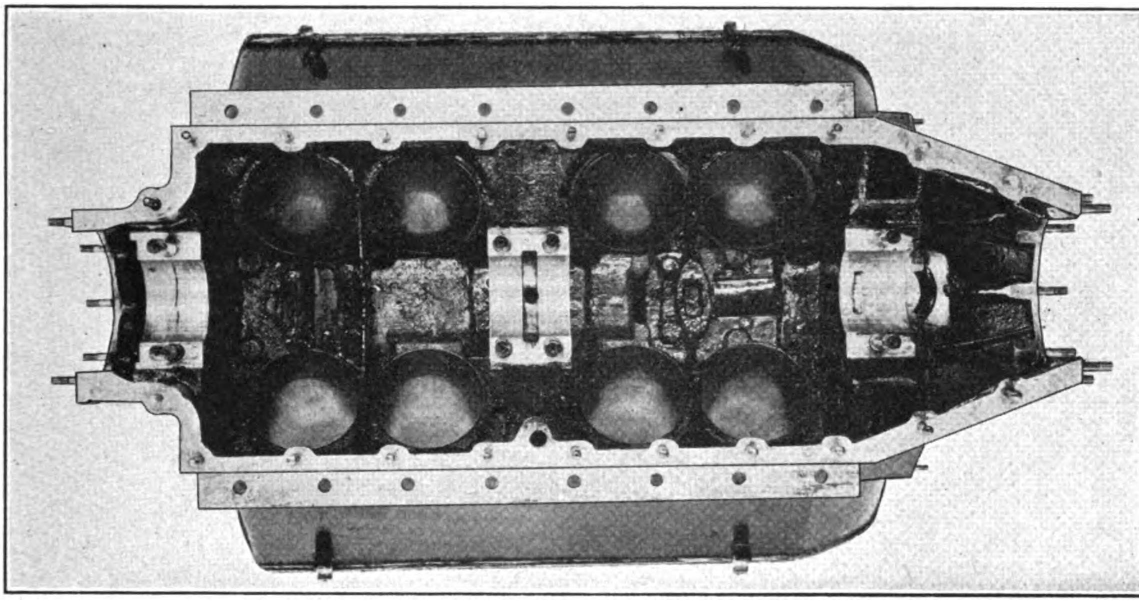


FIG. 6.—Crankcase, upper half, inside view.

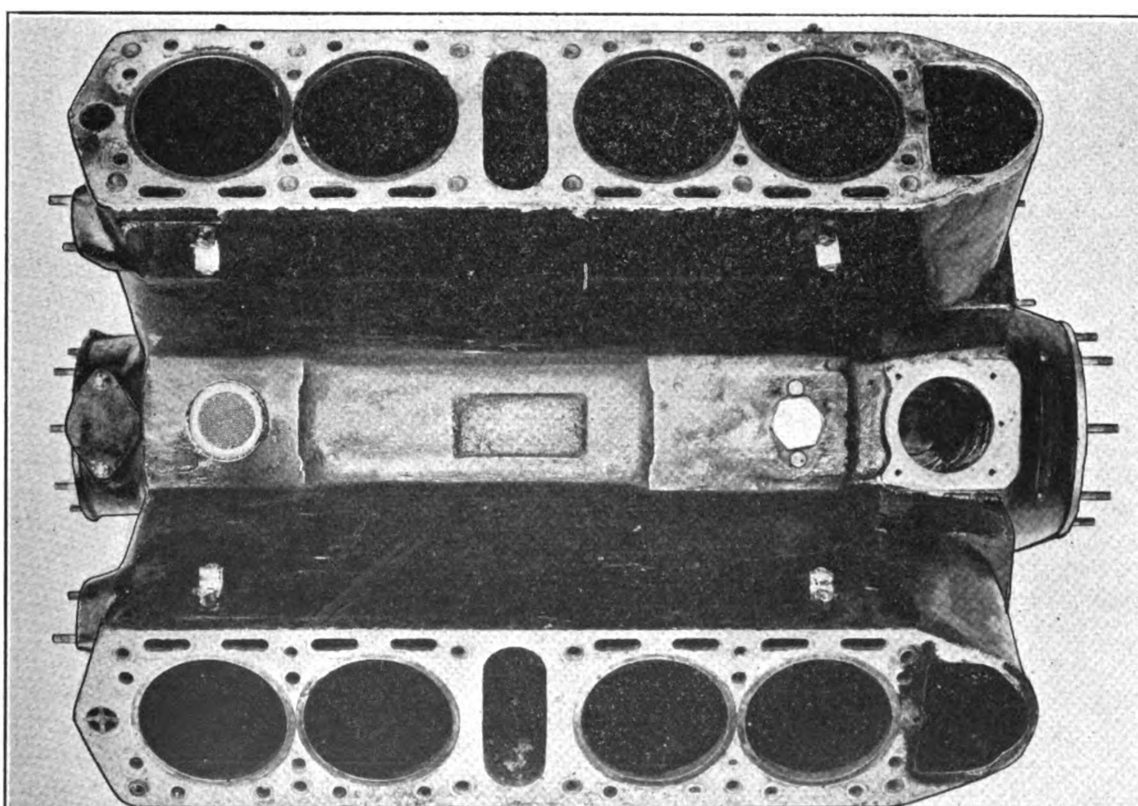


FIG. 7.—Crankcase, upper half, outside view.

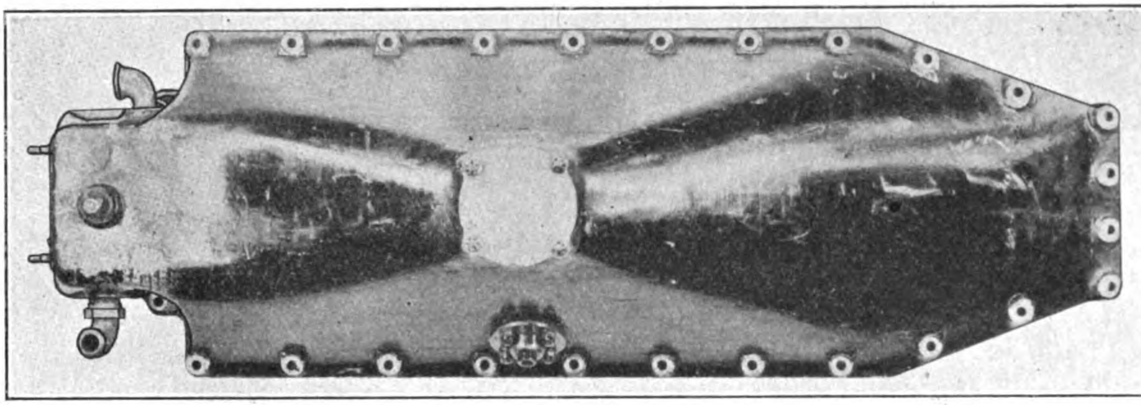


Fig. 8.—Crankcase, lower half, outside view.

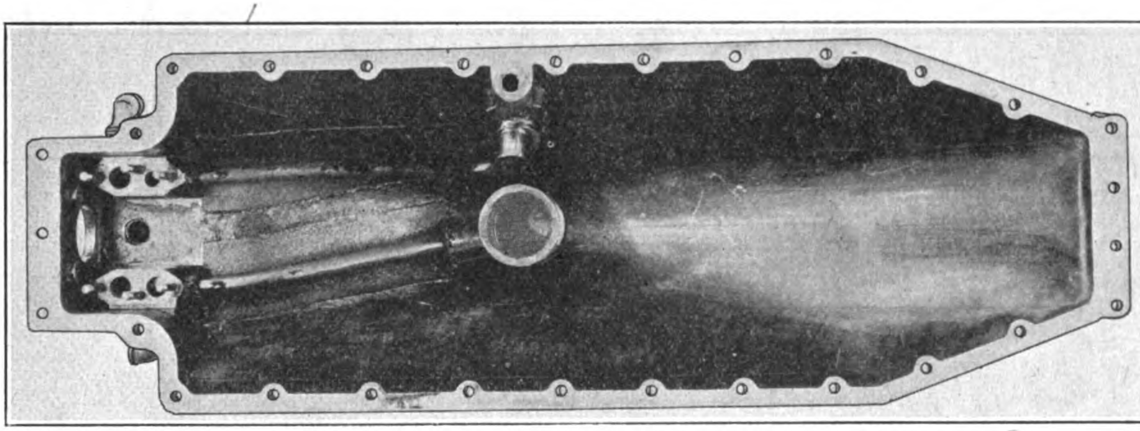


Fig. 9.—Crankcase, lower half, inside view.

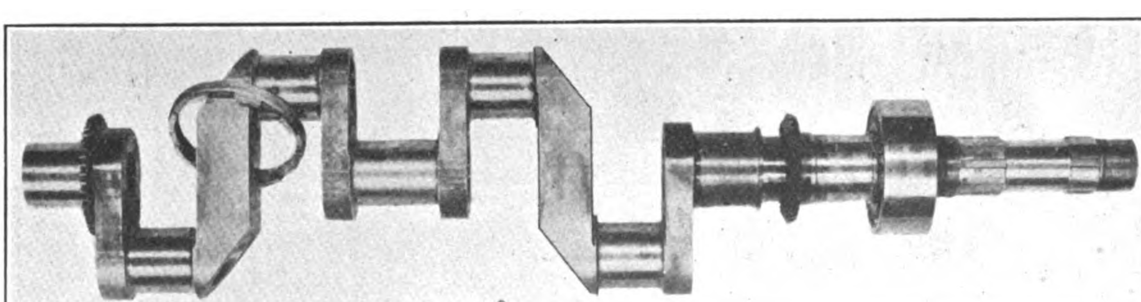


Fig. 10.—Crankshaft.

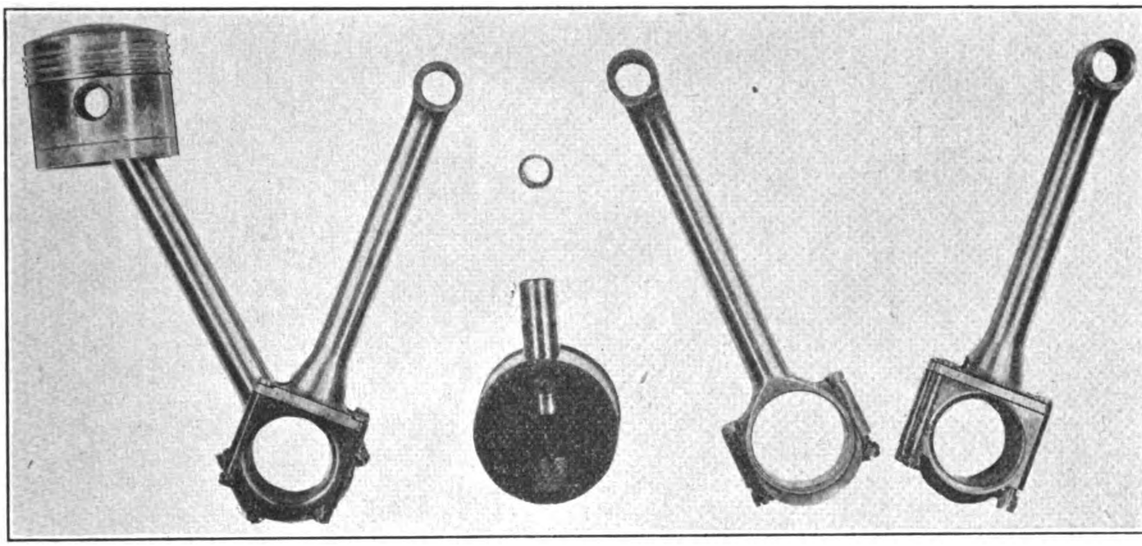


FIG. 11.—Piston and rods.

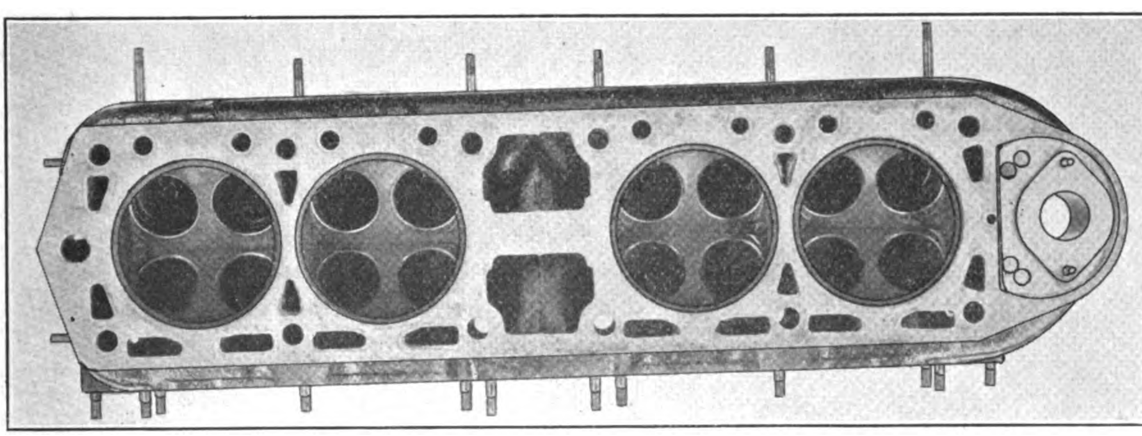


FIG. 12.—Lower view of cylinder head casting.

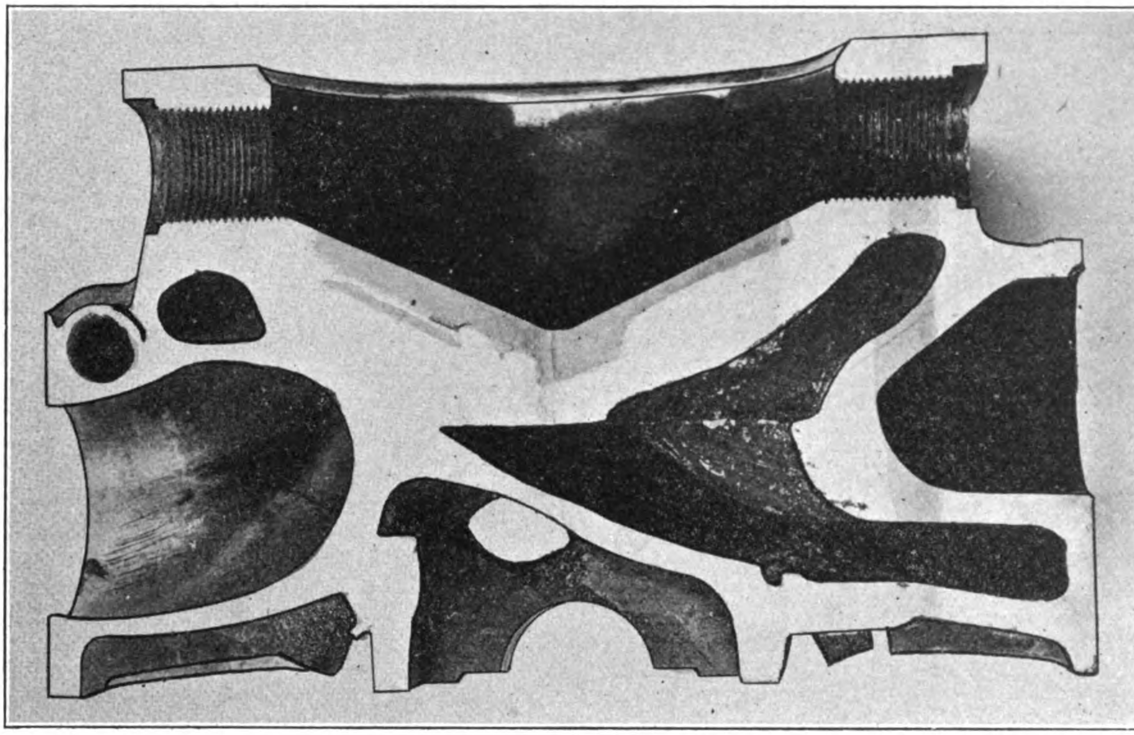


FIG. 13.—Sectional view of cast aluminum cylinder head.

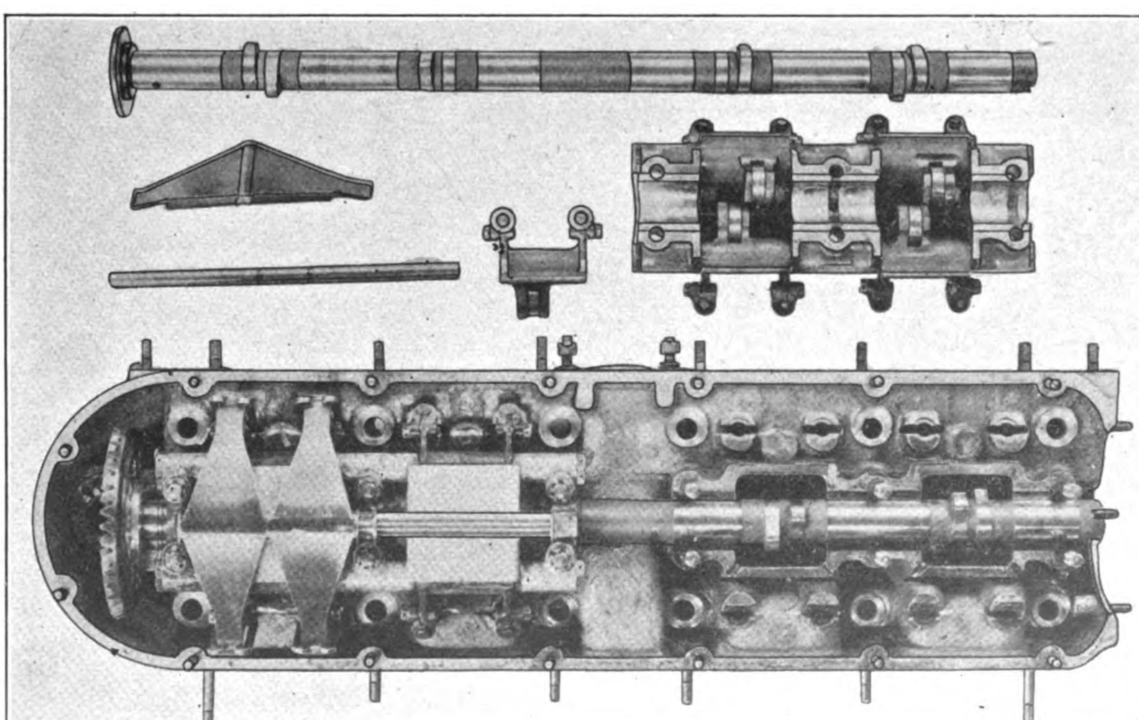


FIG. 14.—Cylinder head assembly with camshaft rockerarms and springs.

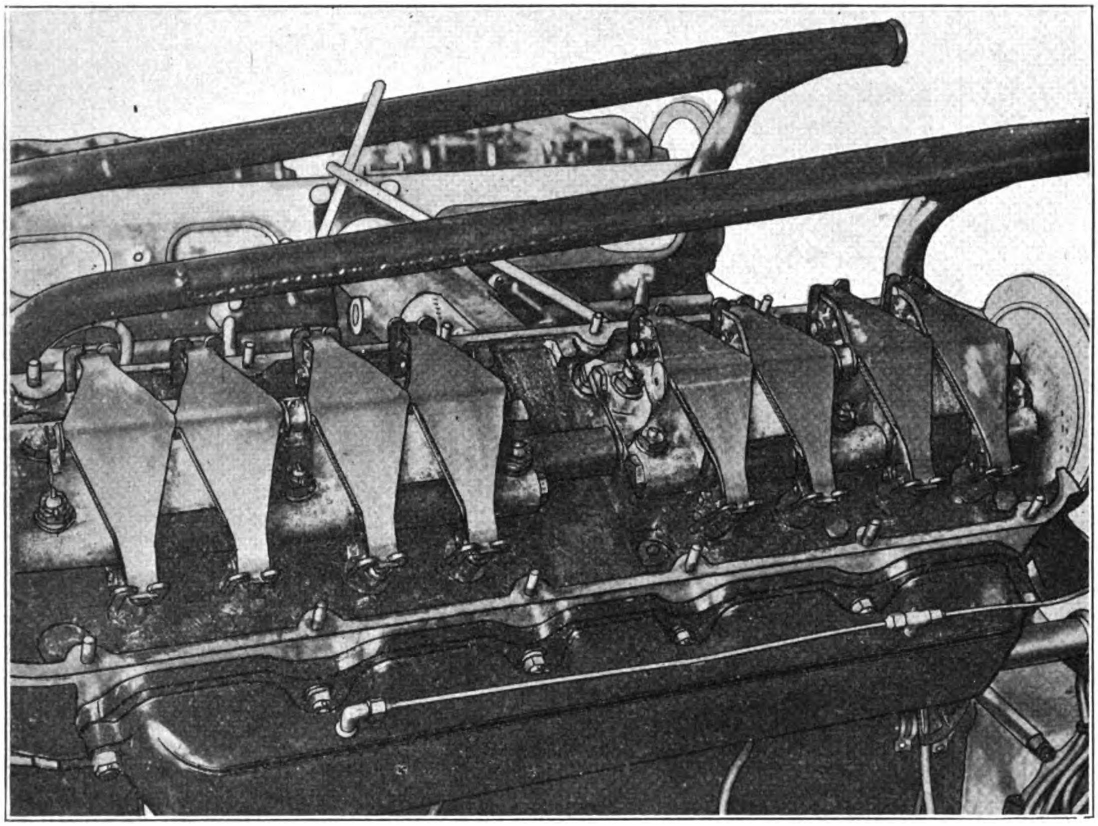


FIG. 15.—View of head, with cover removed, showing valve gear and flat springs.

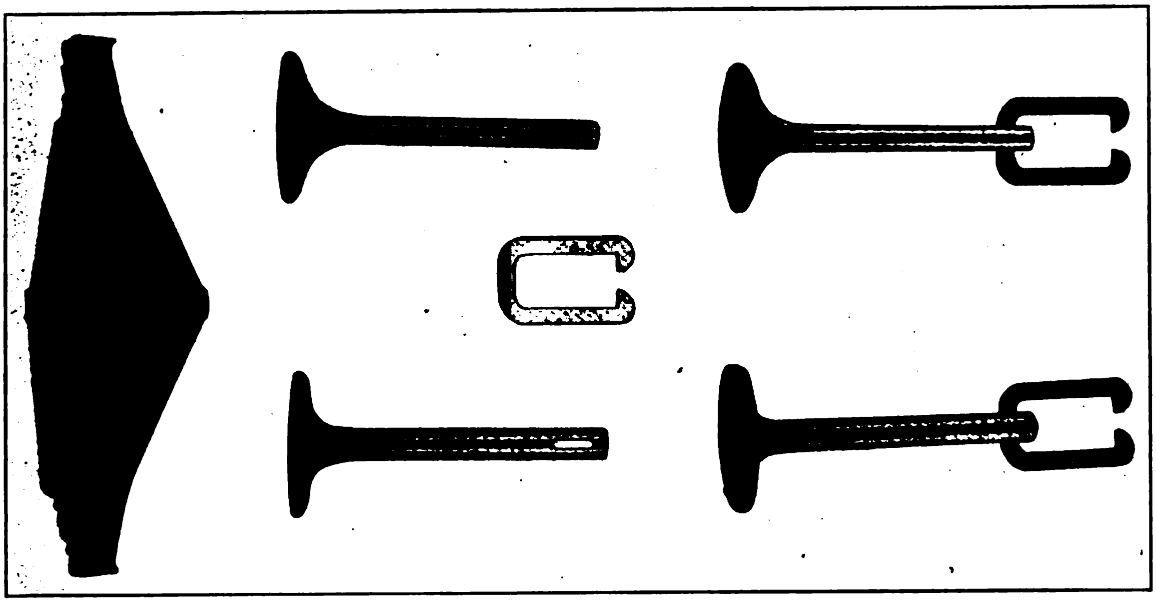


Fig. 16.—Valves and springs.

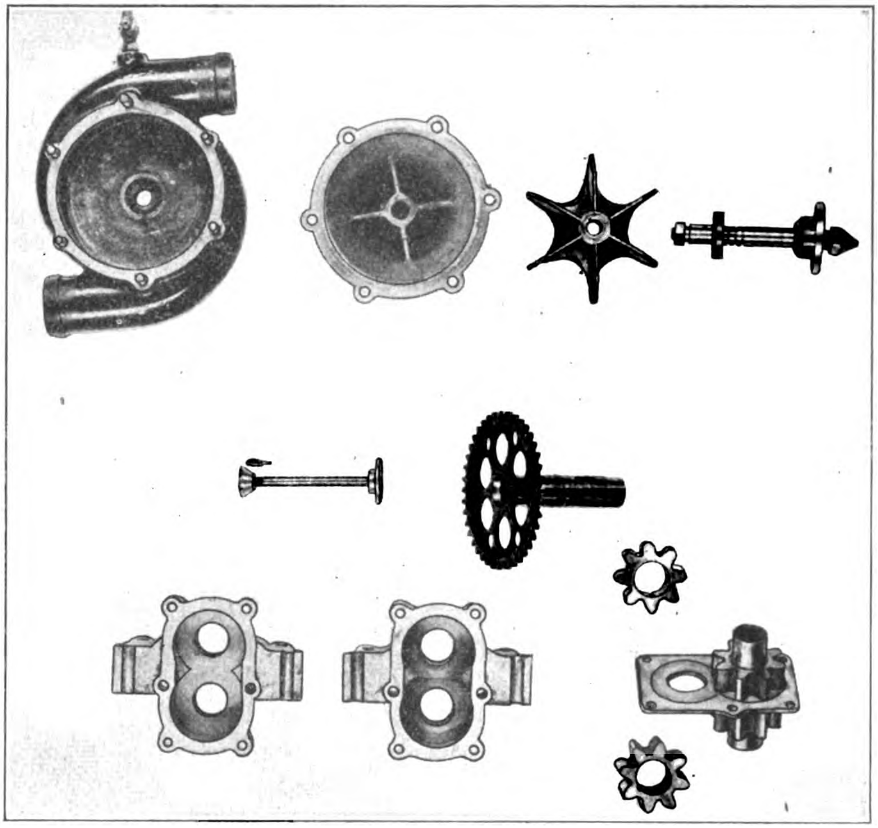


FIG. 17.—Water and oil pumps, disassembled.

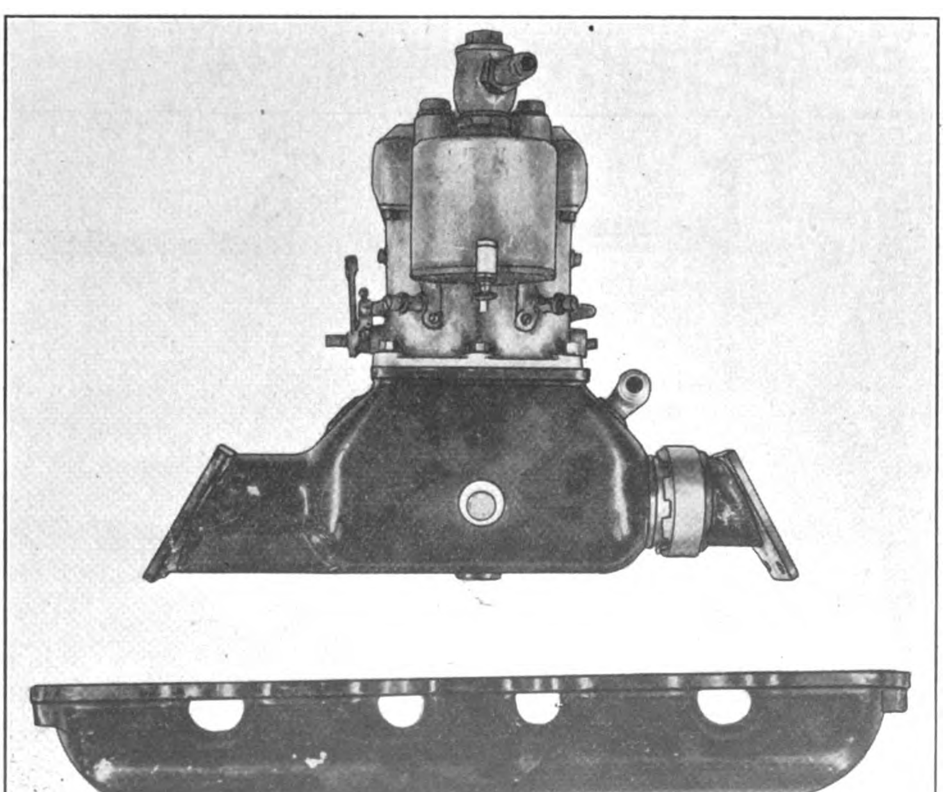


FIG. 18.—Carburetor and intake manifold.

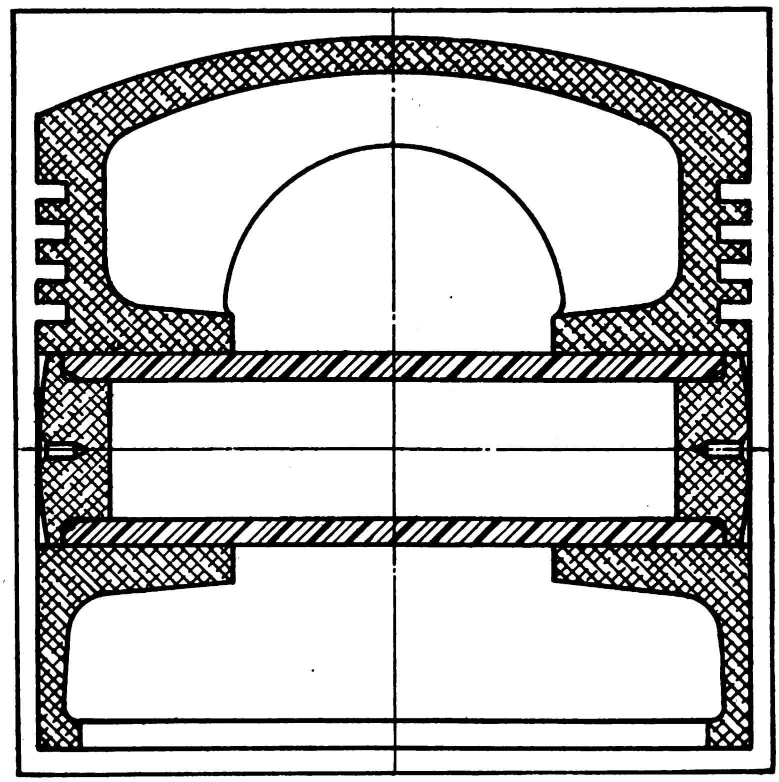


FIG. 19.—Sectional view of piston.

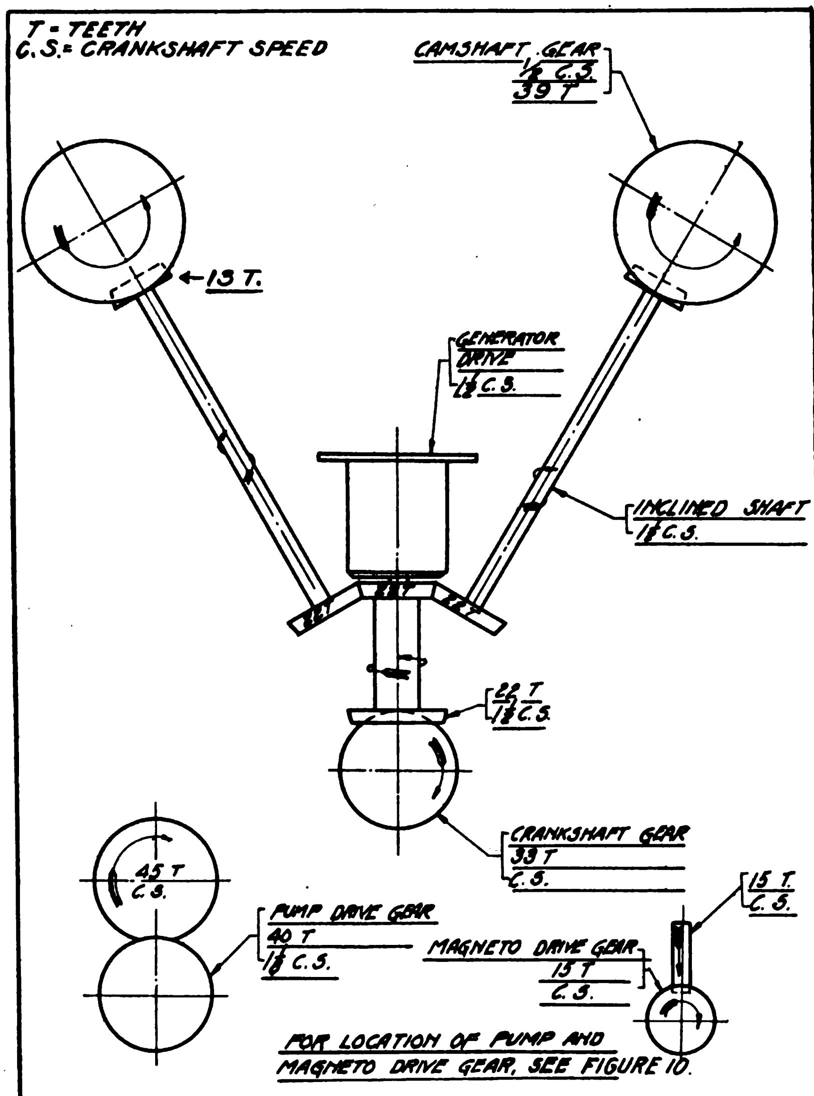


FIG. 20.—Diagram of accessory drive train.

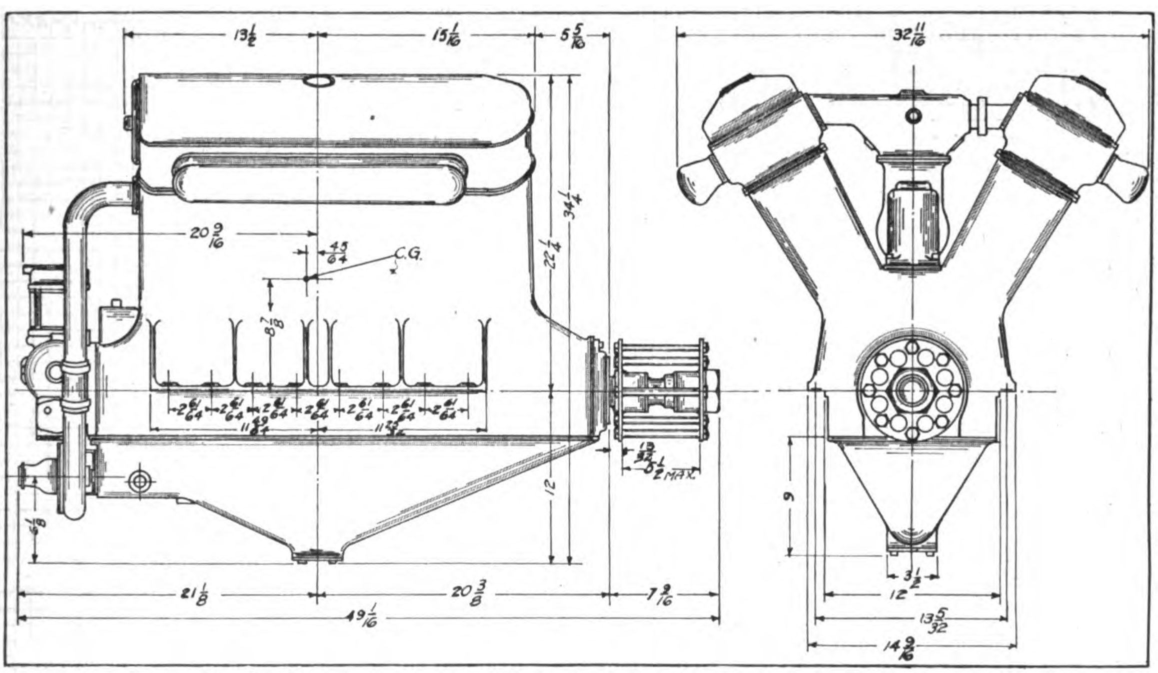


FIG. 21.—Installation diagram.

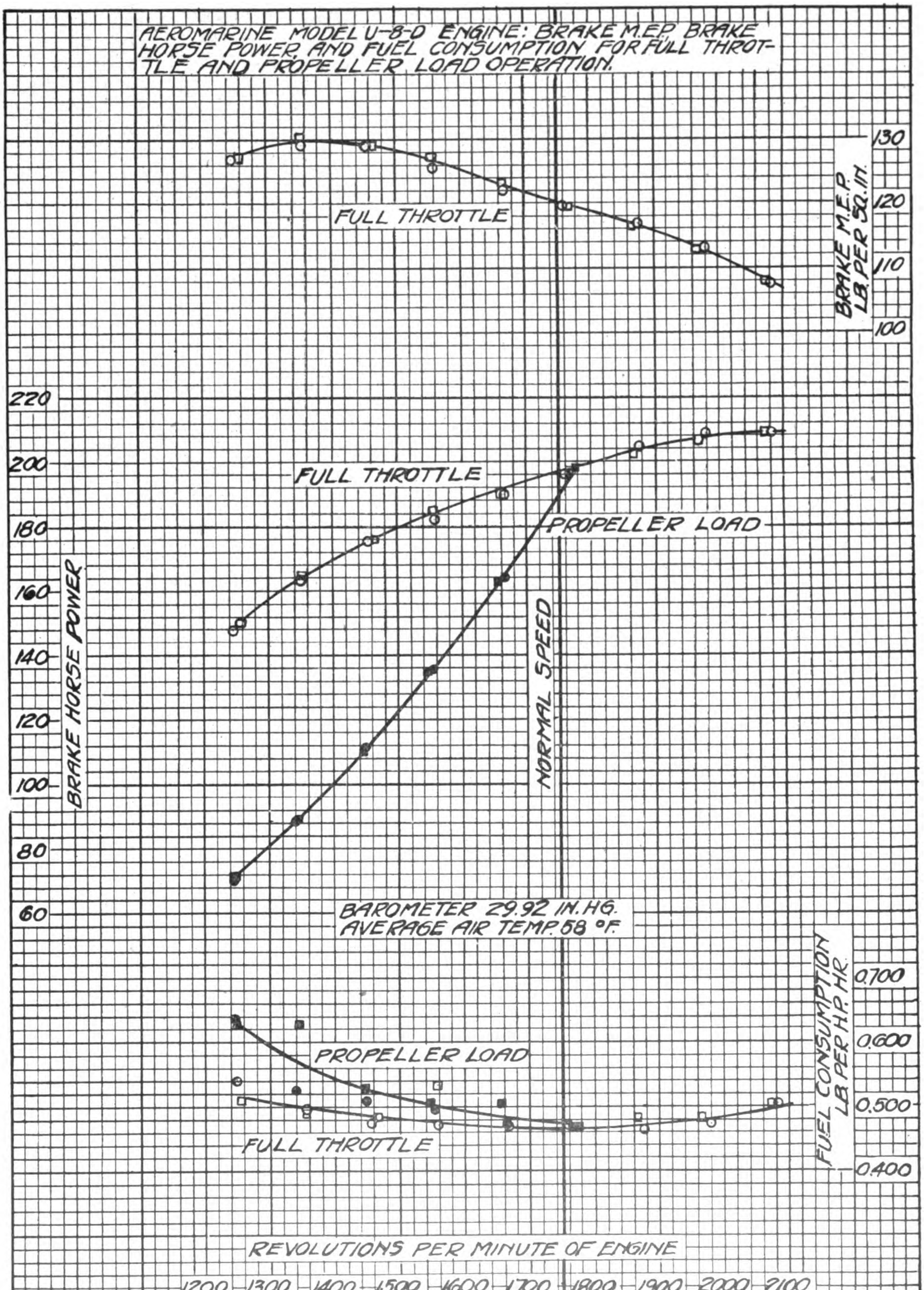
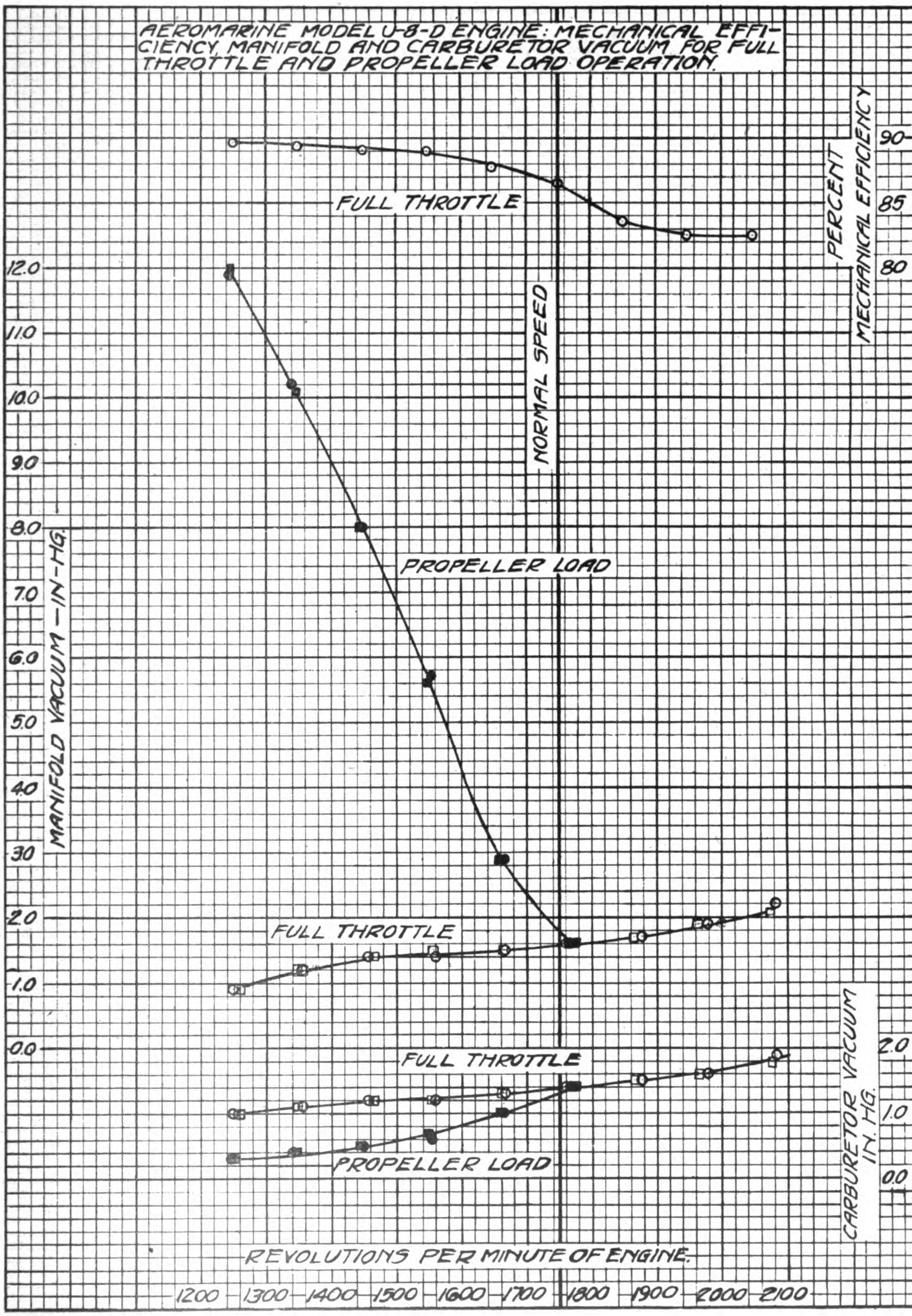

AEROMARINE MODEL U-8-D ENGINE: BRAKE M.E.P. BRAKE HORSE POWER AND FUEL CONSUMPTION FOR FULL THROTTLE AND PROPELLER LOAD OPERATION.
FULL THROTTLE
BRAKE M.E.P. LB. PER SQ. IN.
130
120
110
100
220
200
180
160
140
120
100
80
60
BRAKE HORSE POWER
FULL THROTTLE
PROPELLER LOAD
NORMAL SPEED
BAROMETER 29.92 IN. HG.
AVERAGE AIR TEMP. 58 °F.
PROPELLER LOAD
FULL THROTTLE
FUEL CONSUMPTION LB. PER H.P. HR.
0.700
0.600
0.500
0.400
REVOLUTIONS PER MINUTE OF ENGINE
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100

FIG. 22.



AEROMARINE MODEL U-8-D ENGINE: MECHANICAL EFFICIENCY, MANIFOLD AND CARBURETOR VACUUM FOR FULL THROTTLE AND PROPELLER LOAD OPERATION.
FULL THROTTLE
PERCENT MECHANICAL EFFICIENCY
90
85
80
NORMAL SPEED
MANIFOLD VACUUM - IN. HG.
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
PROPELLER LOAD
FULL THROTTLE
FULL THROTTLE
PROPELLER LOAD
CARBURETOR VACUUM IN. HG.
2.0
1.0
0.0
REVOLUTIONS PER MINUTE OF ENGINE.
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100

Fig. 23.

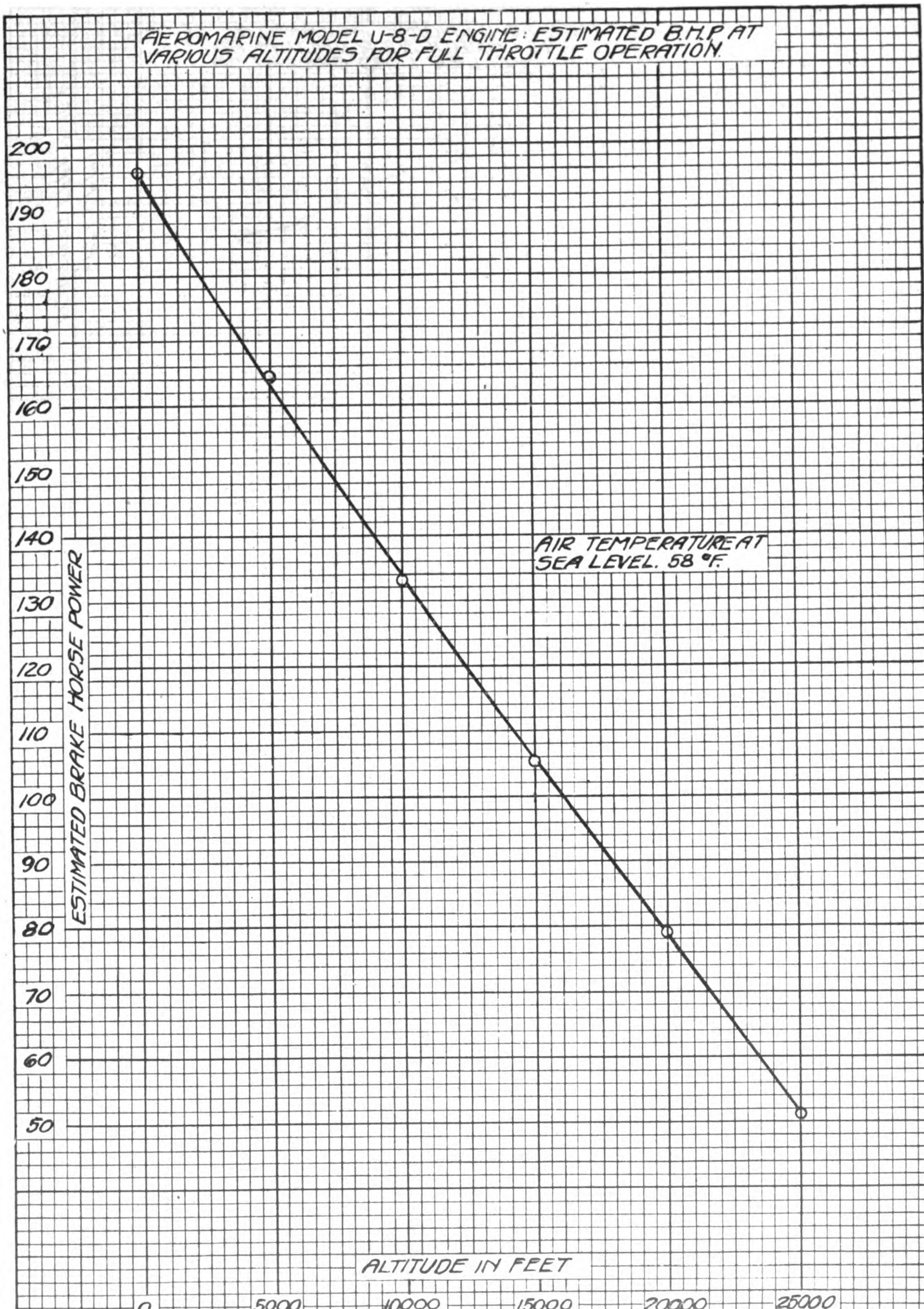

AEROMARINE MODEL U-8-D ENGINE: ESTIMATED B.H.P. AT VARIOUS ALTITUDES FOR FULL THROTTLE OPERATION.
ESTIMATED BRAKE HORSE POWER
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
AIR TEMPERATURE AT SEA LEVEL. 58 °F.
ALTITUDE IN FEET
0
5000
10000
15000
20000
25000

Fig. 24.

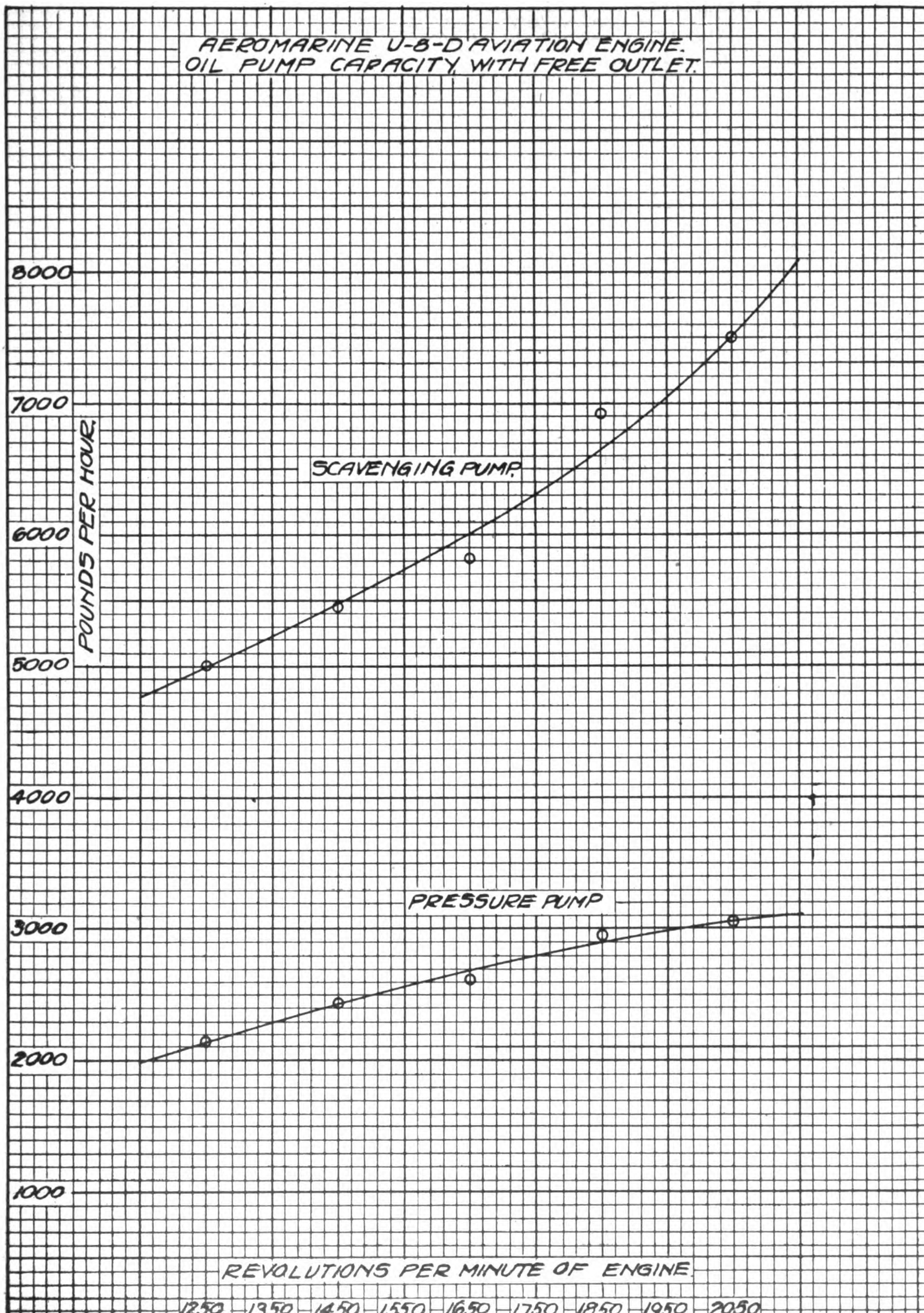

AEROMARINE U-8-D AVIATION ENGINE.
OIL PUMP CAPACITY, WITH FREE OUTLET.
SCAVENGING PUMP.
PRESSURE PUMP
POUNDS PER HOUR.
8000
7000
6000
5000
4000
3000
2000
1000
REVOLUTIONS PER MINUTE OF ENGINE.
1250
1350
1450
1550
1650
1750
1850
1950
2050

FIG. 25.

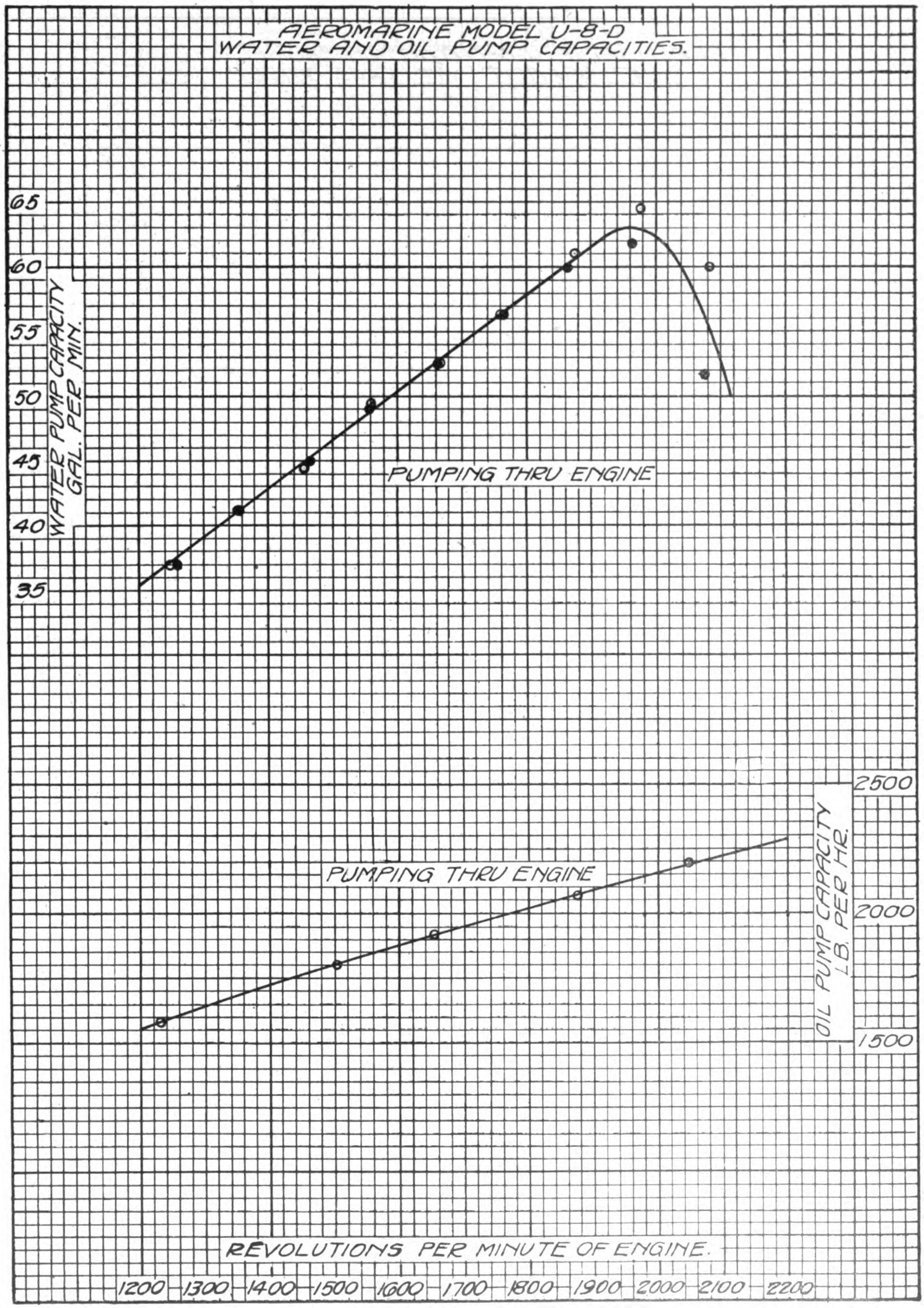

AEROMARINE MODEL U-8-D
WATER AND OIL PUMP CAPACITIES.
WATER PUMP CAPACITY
GAL. PER MIN.
65
60
55
50
45
40
35
PUMPING THRU ENGINE
PUMPING THRU ENGINE
OIL PUMP CAPACITY
LB. PER HR.
2500
2000
1500
REVOLUTIONS PER MINUTE OF ENGINE.
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200

FIG. 26.

[redacted]
File D 52.41 / W-1 / 2

McCOOK FIELD REPORT, SERIAL No. 1765

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV — March 15, 1922 — No. 326

FIFTY-HOUR ENDURANCE RUN OF MODEL W-1 ENGINE

(FIRST EXPERIMENTAL MODEL)

(POWER PLANT SECTION REPORT)

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
October 3, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

Certificate: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INDEX.

FIFTY-HOUR ENDURANCE RUN OF MODEL W-1 ENGINE (FIRST EXPERIMENTAL MODEL).

OBJECT OF TEST.

The object of this test was to determine for developmental purposes the reliability and durability of the model W-1 engine (first experimental model).

RESULTS.

The operation of the engine while running was good. It was run idling at a speed of 400 revolutions per minute without any irregularity. The acceleration was good throughout the range from idling to full-throttle operation. The fuel and oil consumption were low. The power output varied but little during the test. Considerable oil leakage was apparent throughout the test through the passages in the crank case which accommodated the induction pipes.

There were numerous failures of minor parts and replacements made necessary by excessive wear during the test. However, compared with other first experimental engines, the engine performed remarkably well.

The final failure of the crank case of the first design (see fig. 18), which was inherently weak, caused the test to be discontinued after running 44 hours and 45 minutes.

The general condition of the major parts, with the exception of the crank case, was good. The main bearings and connecting-rod bearings were in excellent condition after a run of this duration. For a detailed description of the engine after test, see "Inspection after test," pages 9 and 10.

RECOMMENDATIONS.

The following changes in the model W-1 engine are recommended:

CRANK CASE (UPPER).

The new design which is now being made by the Engineering Division will afford greater strength to this part. A heavier web will be made at that portion of the crank case which accommodates the induction pipes. The web will continue straight back to the wall instead of following the contour of the induction-pipe hole. The opening in the webs which were made to reduce the weight will be made smaller and the webs will be beaded to give greater stiffness.

CRANK CASE (LOWER.)

Strengthening of the webs similar to that in the upper crank case will also be done in the lower crank case.

CRANK CASE (PAN).

Provision should be made to allow bolting the carburetor to the crank-case pan rather than to the induction pipes. Provision should be made to prevent oil leakage at the induction pipes.

CRANK SHAFT.

The oil plugs in the crank shaft should be recessed to obviate the possibility of obstructing the oil holes.

PROPELLER HUB.

The pitch of the front cone should be made steeper.

PISTONS.

Provision should be made for better oil drainage by enlarging the oil return holes and recessing under the lower ring.

CAM-SHAFT ASSEMBLY.

The cam-shaft covers should be stiffened. The cam-shaft housing should be stiffened by means of additional ribbing.

CYLINDERS.

It is recommended that, in order to assure better alignment of the cam-shaft assembly, the studs should be screwed into the cylinders after welding, instead of before as was done with this engine. The lower portion of the cylinder should be strengthened by making the flange heavier.

VALVES.

The junction of the head and stem should not be relieved. Provision should be made for putting valve safety wires in the valve stems.

VALVE GUIDES.

An investigation should be made in an effort to secure better valve-guide material.

VALVE RETAINING COLLARS.

The valve retaining collars should be strengthened.

VALVE TAPPETS.

The casehardening on the valve tappet should be deepened.

COOLING SYSTEM.

The assembly of the water manifold to the cylinders should be simplified. The water pump will be redesigned. The new design will have a shoulder on the impeller shaft supported by a bronze bushing to prevent the impeller scraping the pump case. There will be three outlets on the pump, one of which can handle the water discharge alone while the discharge can be taken care of by the other two when the first is blanked off. A drain plug of new design will be incorporated in the lower part of the pump making it possible to drain the cooling system by screwing off a spanner nut. This nut also provides a seat for a gasket held against the drain passages when screwed up tight.

CARBURETORS.

The carburetors should have single venturi equipment.

ACCESSORY DRIVE BEARINGS.

The cam shaft, water, and oil pump drive shaft bronze bearings will be replaced by ball bearings.

TACHOMETER DRIVE.

The tachometer drive will be taken from the cam shaft and run at cam-shaft speed.

IGNITION SYSTEM.

The distributor blocks should be redesigned. There is a tendency in the present design for sparks to jump from one terminal to another. The terminal nuts are too close for practical manipulation in service.

The method of fastening the block is unsatisfactory, as it requires too much side clearance between magnetos.

There is a tendency on the inside of the block for sparks to jump between the segments and the distributor gear. More room may be gained at the bottom of the block by eliminating the felt cam wiper and flattening the top of the breaker cover. This will allow a groove to be turned on the inside between the segments of the larger diameter in the distributor block and the back edge, thus eliminating the tendency to spark.

Greater care should be taken in riveting the breaker contact rivet, also the rivet holding copper grounding strip to the breaker bar.

INTRODUCTION.

The model W-1 aviation engine is an 18 cylinder "W" type engine consisting of three banks of six cylinders each, with an included angle of 40 degrees between each bank. It was designed by the Engineering Division. The bore is $5\frac{1}{2}$ inches and the stroke $6\frac{1}{2}$ inches. The cylinders are steel forgings with a welded water jacket of sheet-steel stampings. There are four valves per cylinder. The valves are operated by overhead cam shafts through rocker arms. The cylinders are mounted separately on the crank case and are held down by means of six studs and nuts for each cylinder, one of the studs being common to two cylinders. Ignition is furnished by three magnetos mounted on the rear of the engine. The carburetion is furnished by six single carburetors mounted underneath the engine, three on a side.

Where reference is made to the right or left bank the point of observation is assumed as the pilot's seat. The cylinders are numbered from the antipropeller end.

Two views of the engine assembly may be found in figures 1 and 2.

METHOD OF CONDUCTING TEST.

Preliminary power runs were made on this engine and reported in a memorandum from the engineer in charge, power plant laboratory to the chief, power plant section, under date of May 17, 1921.

This test was conducted at McCook Field, Dayton, Ohio. The engineer conducting the test was J. R. Walsh. The test was begun March 28, 1921, and was completed May 6, 1921.

Prior to mounting on the torque stand the engine was given preliminary calibration runs on the dynamometer. These runs consisted of a full-power calibration run with a carburetor setting limiting the power output to 700 horsepower at 1,700 revolutions per minute, a friction horsepower run, a propeller load run, and a run to determine the maximum and minimum heads of gasoline at which the engine would function. The same setting was used during the endurance run.

The engine was then mounted on a torque stand in the open air and fitted with a propeller absorbing the full power of the engine at the normal speed of 1,700 revolutions per minute.

The 50-hour endurance run was divided into 10 periods of 5 hours each. The first half hour of each 5-hour period was run at full throttle. During the remaining $4\frac{1}{2}$ hours the engine was run at nine-tenths power at 97 per cent of the full-throttle speed as determined by the propeller characteristics. Between each 5-hour period a stop was made and the engine given a careful external inspection.

At the start of the test, the propeller was bolted to the engine hub, balanced and tracked. The engine was thoroughly cleaned externally. The gasoline and oil lines were checked. The spark, throttle, and mixture control were checked to insure maximum movement. At the beginning of each period the lubrication system was filled with warm oil, the engine was turned over several times, primed and started immediately. It was run throttled under 1,000 revolutions per minute until the oil had reached a temperature of 100° F.

During the test, note was made of all difficulties encountered. At 15-minute intervals the following readings were taken:

Revolutions per minute (by counter).
Oil temperature.
Oil pressure.
Water temperature (entering and leaving cylinders).
Manifold vacuum.
Atmospheric pressure (barometer).
Fuel consumption.
Oil consumption.
Air temperature.

The fuel and oil consumption was obtained by reading the supply scales at 15-minute intervals.

The data obtained at 15-minute intervals were computed into hourly averages. An exception was made, however, for the one-half hour runs at full throttle, and for discontinuous runs of less than an hour duration, which were averaged separately.

Owing to the many variable errors in the use of the ordinary cradle stand and absorption propeller for measuring torque reaction, the power output was computed by the method described below.

The assumption is made that during the first half hour run on the torque stand, the engine will develop the same power that it did at the corresponding speed on the dynamometer. The horsepower developed during the first half hour on the torque stand was therefore obtained from the dynamometer power curve. The point thus obtained was taken to be a point on the power absorption curve of the propeller, and a curve conforming to the cube law of power-speed relation was therefore drawn through this point. (See fig. 6.) The power developed by the

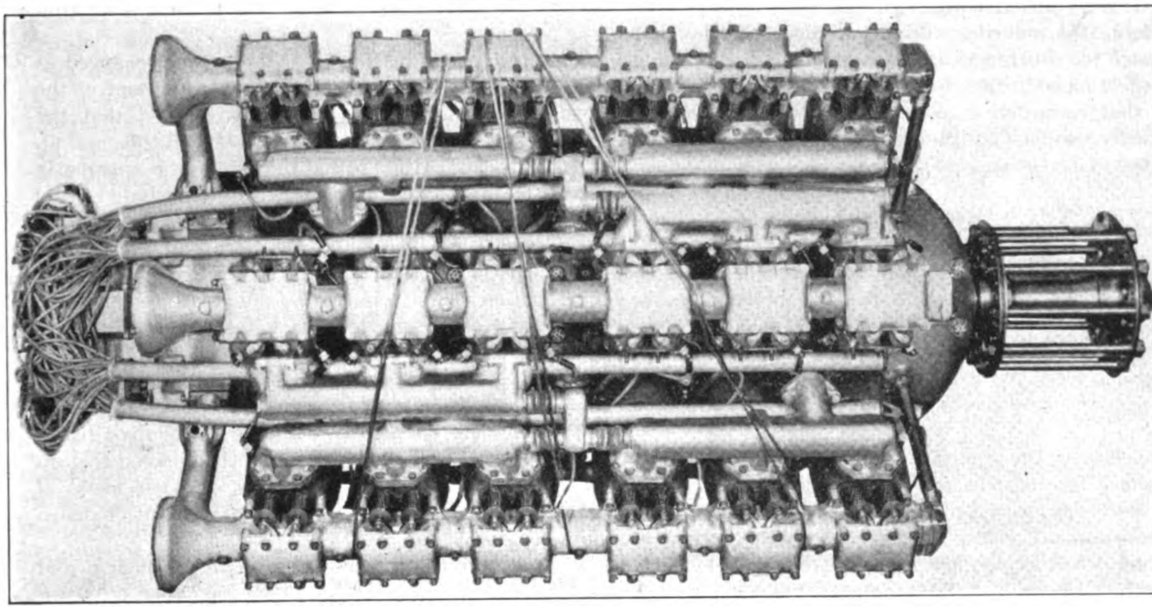


Fig. 1.—Plan view.

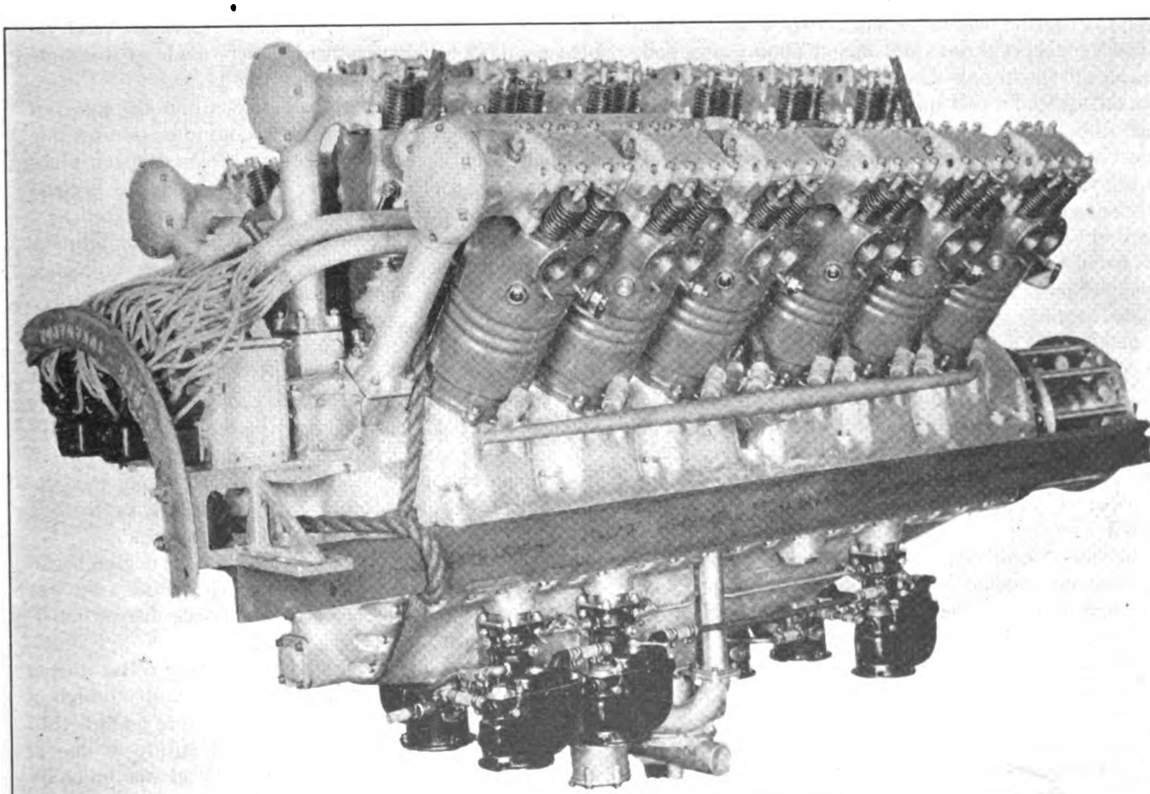


Fig. 2.—Right rear three-quarter view.

engine at any time subsequent to the first half hour was taken directly from this curve.

In using the propeller calibration curve no allowance was made for differences in atmospheric conditions and their effect on propeller characteristics, since it has been found that variations in power due to these differences are usually smaller than the error due to changes in wind direction and velocity.

ANALYSIS.

Dynamometer test results and summarized results by hourly averages of the 50-hour run are included in the data sheets, pages 15 to 17. With varying fuel head on the dynamometer the operation was regular at heads from 1 foot to 16.5 feet. With a head of 0.5 foot the operation was irregular. Best power was obtainable with a head of 7 feet.

While making the preliminary runs on the dynamometer the bronze bearings, in which the water and oil pump drive shafts run, were burnt out (see fig. 10) due to lack of lubrication. The only lubrication supplied to them at that time was the overflow from the cam-shaft housing. When the bearings were replaced provision was made for supplying direct lubrication to these bearings and no further trouble was encountered throughout the test. In the improved design the bronze bearings will be replaced with ball bearings.

Considerable trouble was experienced with the water pump while running the engine on the dynamometer. The bronze button which supported the impeller shaft wore in a very short time sufficiently to allow the impeller to scrape on the pump case. (See fig. 11.) A second bronze button and a cast-iron button also wore badly and similar difficulty was experienced. Substitution of a lignum-vitæ button solved the difficulty.

During the first 10 hours on the torque stand the only trouble encountered was with spark plugs. At the end of the second 5-hour period all the spark plugs were tested. It was found necessary to replace four spark plugs. Three of them had broken porcelains, while the other was fouled.

The first serious trouble occurred 1¾ hours after starting the fourth 5-hour period. At that time a spring-retaining collar of the front intake valve of No. 6 cylinder right bank failed, allowing the valve to drop into the cylinder. As a result the piston was badly battered and broken. A portion of the valve stem was drawn through the induction header and lodged under the intake valve of No. 4 cylinder. No. 6 cylinder was badly damaged and was replaced.

At the time No. 6R cylinder was removed an inspection of the crank case was made through the opening into which the cylinder sleeve passes. It was observed that the web in the upper and lower crank case supporting No. 6 bearing was cracked vertically on each side for its whole depth at the fillet made by the induction passage and the web proper. It was thought that no serious damage would result from further running in this condition, as the crank case was probably cracked after the dynamometer runs, so the test was resumed.

A stop was made three-quarters of an hour later, after 17½ hours' running, when the tachometer drive-shaft key sheared.

A slight water leak was detected in the water jacket of No. 4R cylinder under the cam-shaft housing after running 24½ hours.

The spark plugs in No. 3R cylinder were changed at the end of the sixth 5-hour period. At the end of the seventh 5-hour period an inspection showed that the compression had become poor in No. 4R, 5R, 6R, and 6L cylinders. During this period the engine was apparently getting too lean a mixture even with the altitude control in the full rich position. It was found that several of the valve guides had become badly worn and contributed largely to the poor mixture in the cylinders. Further investigation showed a number of minor failures for which repairs and replacements were necessary. A summary of these changes will be found on page 17.

An inspection made after 38 hours running indicated that the engine required further replacements. Reference to the summary on page 17 will give an itemized list of the changes made at this time. It will be noted that all the outer valve springs on the right and left banks of cylinders were changed to standard Liberty exhaust springs.

Eighteen minutes after starting the ninth 5-hour period trouble was detected in the engine operation. An investigation showed that there was a water leak into No. 1 cylinder. The cylinder was removed and a crack about 4¾ inches long was found at the welded junction of the cylinder head and barrel. A sectional photograph of the cylinder (see fig. 16) shows clearly the method of constructing the cylinder. The crack referred to was very fine. It is not visible in the photograph. Several replacements of minor parts which were made at this time will be found in the summary on page 17.

Two attempts were then made to continue the test, but the engine was stopped after a few minutes running due to trouble in the ignition system. Several spark plugs were changed and the breaker point, which had become loose on the center magneto breaker arm, was replaced.

A valve spring retaining collar failed a few minutes after the next start was made. In this instance no damage was done to the piston or cylinder.

Another start was made, but after running 15 minutes a drop in speed of 150 revolutions per minute necessitated a stop. It was found that the small venturi tube bracket in the front left carburetor broke at a sharp fillet (see fig. 17) and distorted the main discharge nozzle.

A half hour after the next start an identical failure of the bracket occurred on the same carburetor, but the discharge nozzle was unhurt. A water leak in No. 2R cylinder water jacket was detected at this time.

After running 45 hours and 45 minutes the engine began to weave badly and was stopped. The crank case was found to be so badly cracked that the test was discontinued. (See figs. 18 and 19.)

The failure of the valve spring retaining collar during the fifth 5-hour run was evidently due to faulty design of this part. The section at the point of failure was too thin and had a sharp corner. The second failure of one of these parts occurred at the same point and was probably due to the same cause. The retaining collar will be strengthened.

Excessive wear of valve guides occurred frequently during this test. In all 14 replacements were made. A

metallurgical analysis of the valve guides showed that they were made of material which was practically the same as has been successfully used with the Liberty engines. Wear is attributed to stress of service. None of the valve guides in the center bank were replaced. The weak crank case evidently allowed considerable weaving in the right and left banks. In the photographs (figs. 12 and 13) No. 1 had run only 3 hours. The other valve guides had been run for 35 hours.

Valve-spring trouble persisted throughout the run. A metallurgical analysis of the original springs showed them to be of plain carbon steel, which is considered unsuitable for springs of this kind. A large amount of manganese sulphide was present in the steel and may have been a contributary cause to the failures. However, after all the outer springs on the right and left banks had been replaced with standard Liberty exhaust springs, six of these were broken in the following 2 hours and 18 minutes. The Liberty engine springs are made to accommodate a larger valve than those used in the model W-1 engine and stand slightly higher spring pressures. It would seem, therefore, that the valve spring failures might be due to the sharp cam action (quick opening and closing of the valves) or to the weaving of the engine due to the cracked crank case.

It was necessary to replace 13 inlet valve tappets during the run because of excessive wear. The excessive wear of the valve tappets can be attributed to the thin case obtained during the hardening process.

INSPECTION AFTER TEST.

CRANK CASE (UPPER).

The upper crank case was badly cracked in front and under the first three cylinders in each bank. The cracks were interconnecting between the flanges and extended vertically in the webs at the induction-pipe opening. The hollow box web under the center main bearing was cracked and had a depression and thin section on the gear side of the web due to poor casting. The case was chafed at the parting flange. One cylinder to crank-case stud between 4C and 5C and one at the front of 6C were broken. (See fig. 18.)

CRANK CASE (LOWER).

The webs under cylinders Nos. 4 and 5 and between Nos. 5 and 6 cylinders were cracked all the way through. The case was chafed at the parting flange. The bearing backing was chafed. (See fig. 19.)

CRANK SHAFT.

The crank shaft was out of line 0.012 inch at the center bearing.

PROPELLER HUB.

The rear cone and the propeller hub surface on the rear cone were galled.

CONNECTING RODS.

The connecting rods were in good condition. They showed the usual amount of heat at the small end bearing.

MAIN BEARINGS.

All bearings were slightly scratched. Lower bearings numbers 2, 4, 5, 6, 7, and 8 showed uneven wear and the backs of the shells were chafed. In general, the bearings were in excellent condition. (See figs. 21 and 22.)

CONNECTING-ROD BEARINGS.

All the connecting-rod bearings were in excellent condition. (See figs. 23 and 24.)

PISTONS.

Numbers 1R, 2R, 3R, 4R, and 5R pistons had a fairly heavy carbon deposit on the piston head. There was no deposit inside the pistons underneath the head. All the pistons showed wear on the top land. The rings were all free in their grooves. The pistons showed no signs of erosion. The piston skirts were all oil burnt on the antithrust side. There were no "blow-bys." There was no appreciable wear in the piston bosses. (See figs. 25, 26, and 27.)

CAM-SHAFT HOUSING (LEFT BANK).

The cam-shaft housing was porous at 1, 3, 4, and 5 cylinders. The surfaces on the housing under rocker covers Nos. 3 and 4 were chafed. The rocker bearings showed the usual wear. The housing feet were broken at Nos. 1 and 5 cylinders. (See fig. 20.)

CAM-SHAFT HOUSING (CENTER BANK).

The rocker bearings showed the usual wear. One housing foot at No. 6 cylinder was cracked. There were a few porous spots near No. 4 rocker bearing.

CAM-SHAFT HOUSING (RIGHT BANK).

There were porous spots near Nos. 1, 3, 5, and 6 cylinders. The rocker bearings showed the usual wear.

CAM SHAFTS.

The cam shafts were in good condition.

CAM-SHAFT BEARINGS.

The cam-shaft bearings were in good condition.

ROCKER ARMS (RIGHT BANK).

All rocker journals showed slight wear and Nos. 1 and 5 were slightly rusted. The valve tappets of Nos. 1, 5, and 6 cylinders were worn excessively.

ROCKER ARMS (LEFT BANK).

There was slight wear on the journals of Nos. 1, 2, and 3 rocker arms. The journals of No. 6 rocker arms were badly worn. Nos. 1, 4, and 5 valve tappets were badly worn.

ROCKER ARMS (CENTER BANK).

All the journals were slightly worn. Nos. 2, 3, and 4 were rusted. No. 6 inlet valve tappets were badly worn.

CAM-SHAFT COVERS (RIGHT BANK).

Both bearing surfaces of Nos. 1, 4, and 5 rocker covers were scored. The bearing nearest the intake valve of Nos. 2 and 3 was scored.

CAM-SHAFT COVERS (LEFT BANK).

The bearings nearest the inlet valve of Nos. 3 and 5 rocker covers were scored. Both bearings of Nos. 1, 4, and 6 were scored.

CAM-SHAFT COVERS (CENTER BANK).

Both bearings of Nos. 1, 2, 3, 4, and 5 were scored slightly. The bearing nearest No. 6 intake valve was slightly scored.

GEARS.

The gear driving the water pump showed uneven wear from improper cutting. The pinions driving the cam shaft were excessively worn. In general the gears showed the usual wear for a run of this duration.

VALVE GUIDES.

All the valve guides on the right and left banks were badly worn. No. 3L front inlet valve guide was broken through its diameter at the junction of the valve guide flange and the cylinder.

VALVES (LEFT BANK).

The front exhaust valves of Nos. 1, 4, and 5 cylinders showed signs of excessive heat, as did both exhaust valves in Nos. 2, 3, and 6 cylinders. All valves had excessive play in guides. Nos. 1, 2, and 3 inlet valves had heavy carbon deposits on the upper side. Both inlet valves in Nos. 1, 2, 3, and 6 cylinders leaked slightly, as did both exhaust valves in Nos. 2, 4, and 5 and the rear exhaust valves in Nos. 1 and 6. No. 3 exhaust valves leaked badly. (All valves were tested with gasoline for leakage.)

VALVES (RIGHT BANK).

All the exhaust valves showed signs of excessive heat. Nos. 2 and 5 rear exhaust valves were scaled. Nos. 1, 2, 3, and 5 intake valves had a heavy carbon deposit on the upper side of the valve head. Both inlet valves in Nos. 1 and 2 cylinders leaked slightly, as did Nos. 4 and 6 exhaust valves. No. 1 front and No. 3 rear exhaust valves also leaked slightly. Both exhaust valves in Nos. 2 and 5 cylinders leaked badly. All the valves were loose in their guides.

VALVES (CENTER BANK).

Nos. 1, 2, 3, 4, 5, and 6 exhaust valves showed signs of excessive heat. Nos. 2, 3, and 6 exhaust valves were badly pitted and scaled. No. 3 front exhaust valve was particularly bad, having a portion of the valve head burnt away. All the valves were loose in their guides. Both intake valves in Nos. 2, 3, 4, 5, and 6 and both exhaust valves in Nos. 1, 4, and 5 leaked slightly. Both exhaust valves in Nos. 2, 3, and 6 leaked badly.

VALVE SPRINGS.

Five intake and 12 exhaust springs were found broken after the test. One of the exhaust springs, an inner spring, was the only spring found broken on the center bank after the test.

VALVE-SPRING COLLAR KEYS.

A number of the valve-spring collar keys were badly worn.

CYLINDERS (LEFT BANK).

The exhaust valve seat of No. 2 cylinder was badly pitted. There was a leak in the water jacket on the head of Nos. 6, 5, 4, and 2 cylinders.

CYLINDERS (RIGHT BANK).

All the valve seats were slightly pitted in Nos. 1 and 3 cylinders. Both exhaust valves were badly pitted in Nos. 2 and 5 cylinders. There was a leak in the water jacket of No. 2 cylinder.

CYLINDERS (CENTER BANK).

The intake valve seats of Nos. 2 and 4 cylinders were slightly pitted. Both exhaust valve seats in No. 2 cylinder were badly pitted. The front exhaust valve seat of No. 3 cylinder was badly pitted. All intake and exhaust valve seats in No. 5 cylinder were slightly pitted.

LUBRICATION SYSTEM.

A flange on the oil manifold was broken.

WATER PUMP.

The lower case and impeller were badly worn by rubbing early in the test. The shaft was slightly rusted. (See fig. 11.)

CARBURETION.

The carburetors were in good condition. Replacements of two small venturi brackets had to be made on one of the carburetors shortly before the test was discontinued. The needle valves and seats showed the usual wear.

IGNITION.

The high-tension coil of the right magneto was punctured.

All other parts were in good condition.

TOTAL REPLACEMENTS DURING 50-HOUR TEST.

Cylinders	2
Valve springs:	
Intake	31
Exhaust	28
Valve guides:	
Intake	7
Exhaust	7
Valves (replaced):	
Intake	3
Exhaust	6
Valves (ground):	
Intake	20
Exhaust	20
Spark plugs:	
Cracked porcelains	16
Fouled	16
Valve spring retaining collar	2
Venturi tube bracket (carburetor)	2
Main discharge nozzle (carburetor)	1
Magneto	1
Magneto breaker	1
Valve tappets (inlet)	13
Pistons	1
Tachometer adapter drive shaft	2

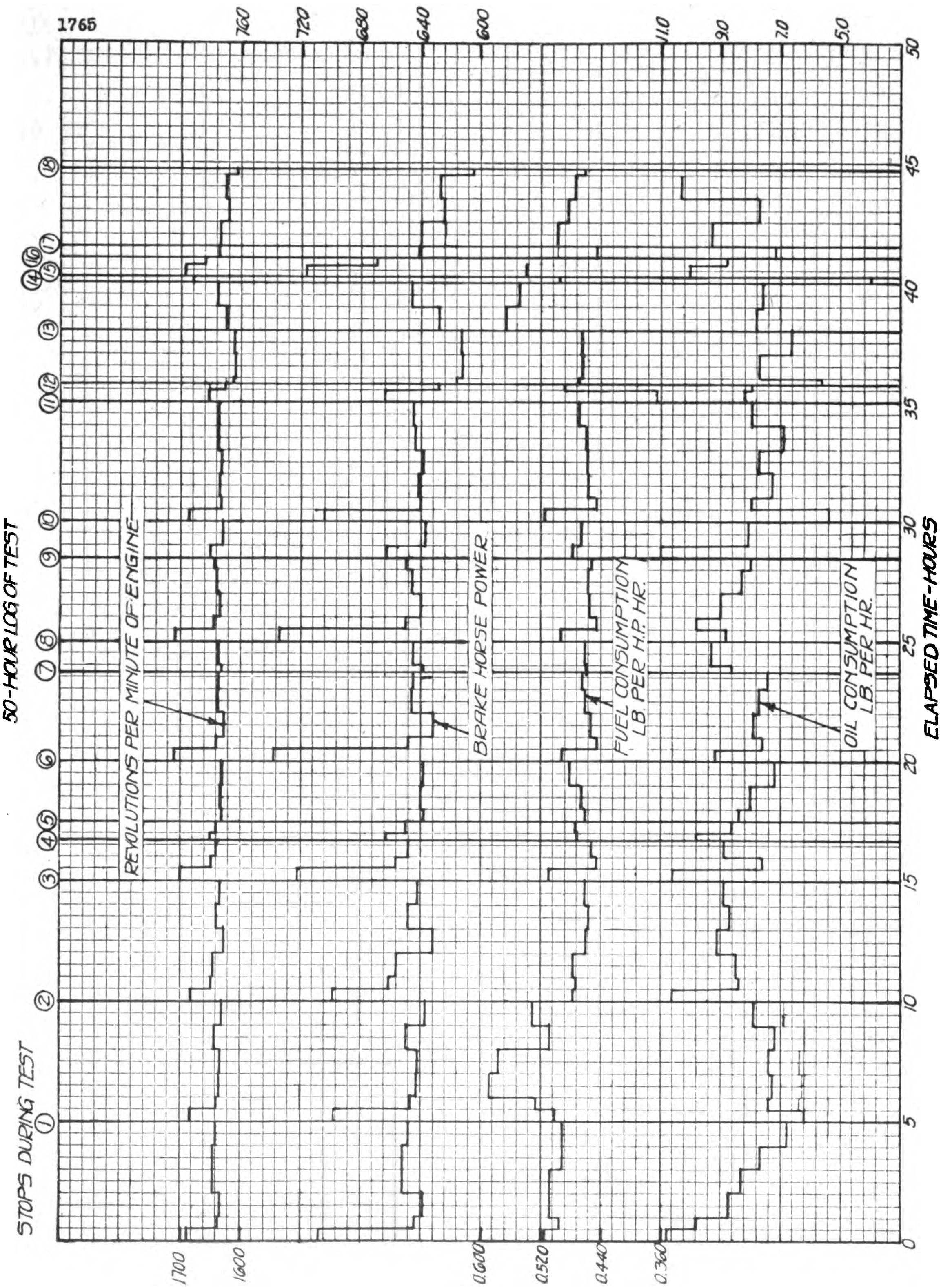

1765
50-HOUR LOG OF TEST
STOPS DURING TEST
REVOLUTIONS PER MINUTE OF ENGINE
BRAKE HORSE POWER
FUEL CONSUMPTION LB. PER H.P. HR.
OIL CONSUMPTION LB. PER HR.
ELAPSED TIME-HOURS
1700
1600
0.600
0.520
0.440
0.360
760
720
680
640
600
11.0
9.0
7.0
5.0
0
5
10
15
20
25
30
35
40
45
50

Fig. 3.

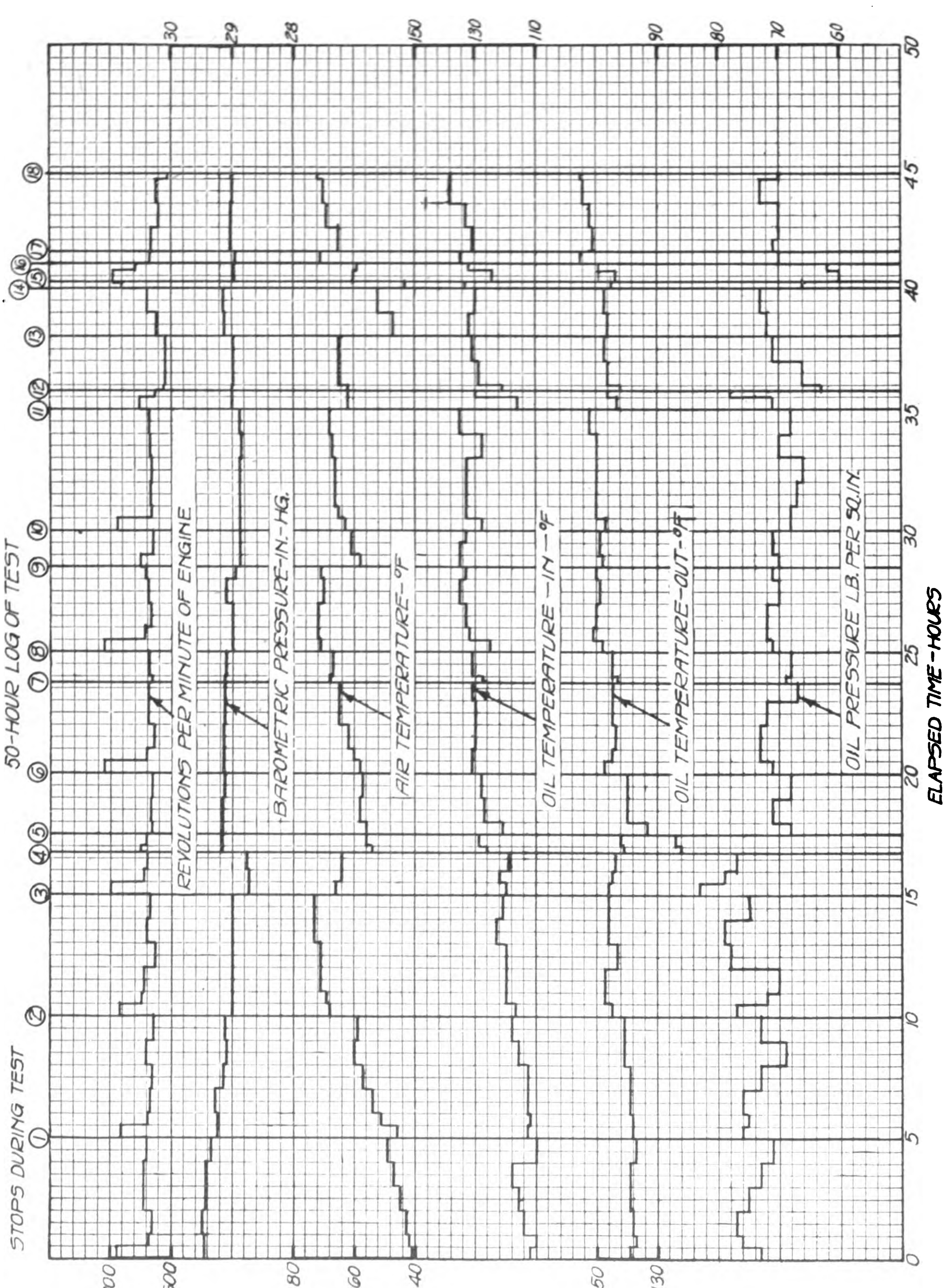

50-HOUR LOG OF TEST
STOPS DURING TEST
REVOLUTIONS PER MINUTE OF ENGINE
BAROMETRIC PRESSURE-IN.-HG.
AIR TEMPERATURE-°F
OIL TEMPERATURE-IN-°F
OIL TEMPERATURE-OUT-°F
OIL PRESSURE LB. PER SQ.IN.
ELAPSED TIME-HOURS
0
5
10
15
20
25
30
35
40
45
50
1700
1600
80
60
40
150
130
30
29
28
150
130
110
90
80
70
60

Fig. 4.

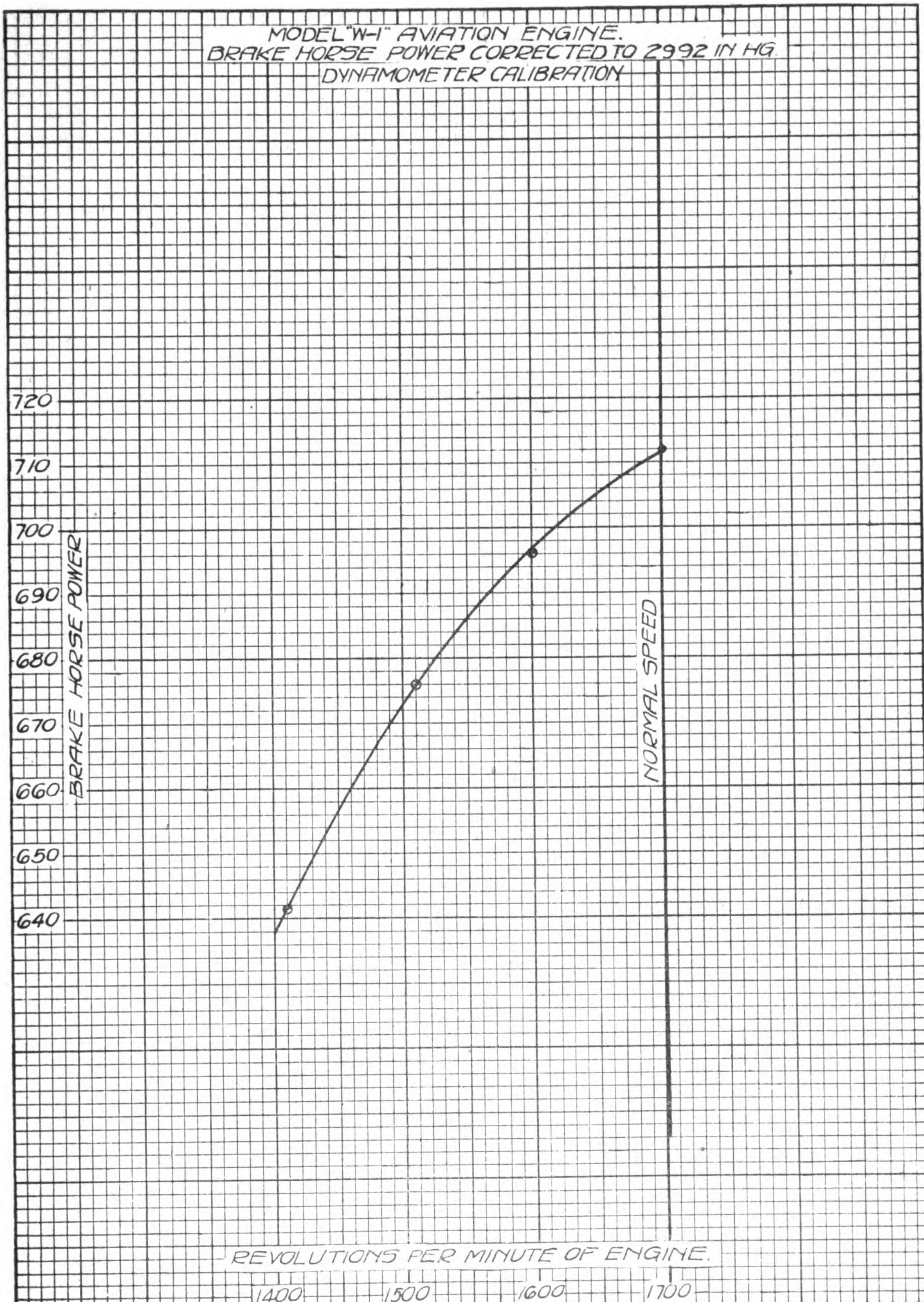

MODEL "W-1" AVIATION ENGINE.
BRAKE HORSE POWER CORRECTED TO 29.92 IN HG.
DYNAMOMETER CALIBRATION
BRAKE HORSE POWER
720
710
700
690
680
670
660
650
640
NORMAL SPEED
REVOLUTIONS PER MINUTE OF ENGINE.
1400
1500
1600
1700

FIG. 5.

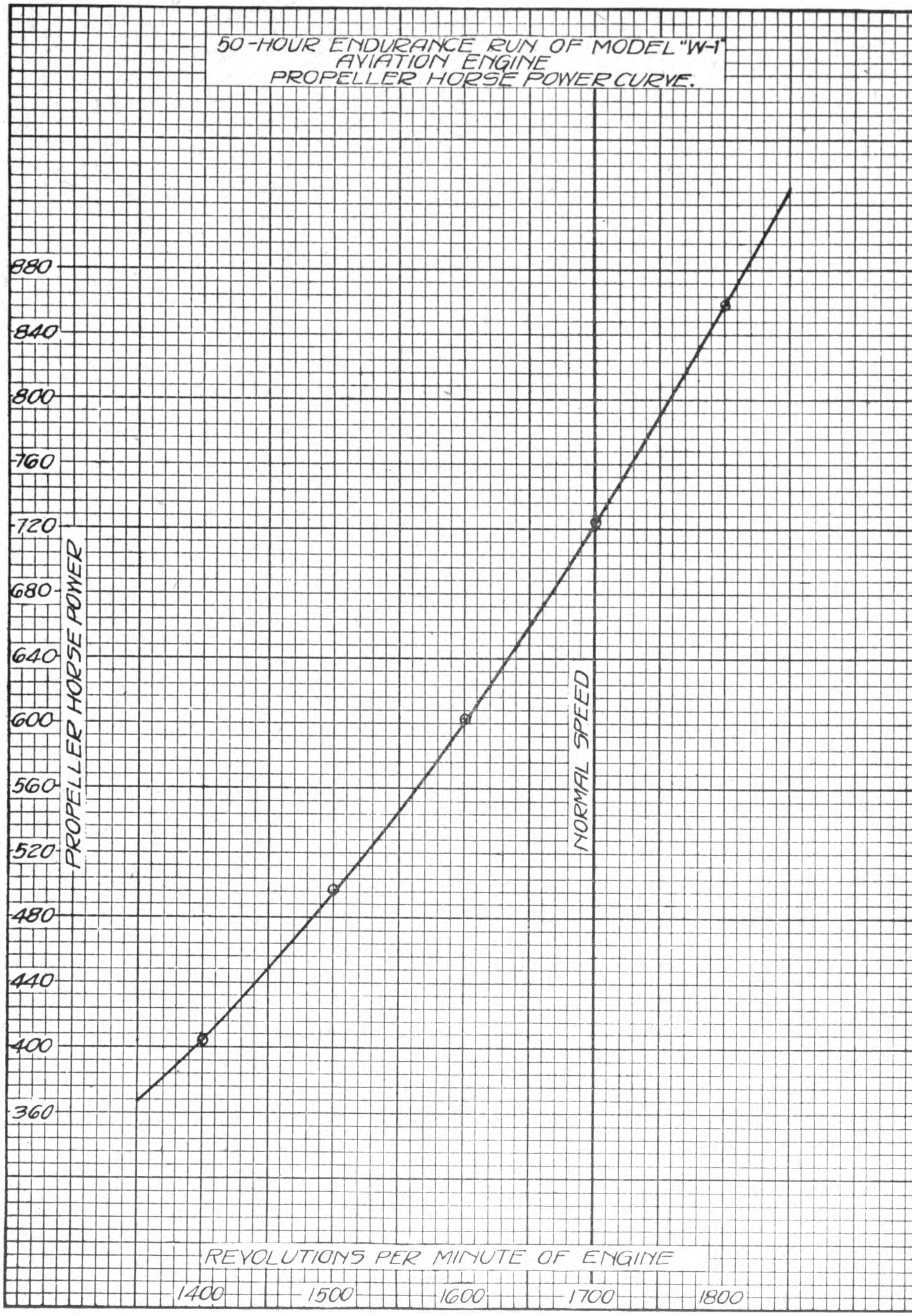

50-HOUR ENDURANCE RUN OF MODEL "W-1"
AVIATION ENGINE
PROPELLER HORSE POWER CURVE.
PROPELLER HORSE POWER
NORMAL SPEED
REVOLUTIONS PER MINUTE OF ENGINE
880
840
800
760
720
680
640
600
560
520
480
440
400
360
1400
1500
1600
1700
1800

Fig. 6.

Full power run.

(CALIBRATION ON DYNAMOMETER.)

R. P. M.	Actual.		Corrected.			Water.		Oil.				Carb. air temp., ° F.	Man. vac. in. hg.	Carb. vac. in. hg.	Gas cons.	
	Brake load, lb.	B.H.P.	Torque, lb.-ft.	H. P.	B. M. E. P., lb. per sq. in.	Temp., ° F.		Temp., ° F.		Press., lb. per sq. in.	Press., lb. per sq. in. cam-shaft housing.				Sec. for 9 lb.	Lb. per hp. hr.
						In.	Out.	In.	Out.							
1,410	1,342	631	2,387	641.4	129.5	146	170	100	130	78	65	50	1.8	0.5	97.4	0.528
1,510	1,321	665	2,350	676.0	127.5	144	170	100	130	75	.65	50	2.0	.5	95.0	.513
1,600	1,284	685	2,283	696.0	123.8	148	170	100	136	76	62	49	2.2	.6	94.6	.500
1,700	1,234	700	2,196	712.0	119.2	146	170	104	144	76	62	48	2.3	.6	[1] 112.0	.505

Carburetor setting: Chokes, 1¾ inches; main jets, No. 44 drill; brake arm, 21 inches; kind of oil used, 50 per cent U. S. Spec. 3501, 50 per cent No. 3550; average barometer, 29.43 in. hg.

NOTE.—The carburetor throttles were adjusted to give 700 horsepower at 1,700 revolutions per minute.

March 28, 1921.

Daily log of run.

TABLE OF AVERAGE RESULTS.

Date.	Time.				R.P.M.	B.H.P. from curve.	Carb. air temp., ° F.	Baro., in. hg.	Water.		Oil.			Man. vac., in. hg.	Carb. vac., in H_2O.	Fuel cons.		Oil cons. (Lb. per hr.)
	Total elapsed.		Duration this run.						Temp., °F.		Temp., °F.		Press., lb. per sq. in.			Lb. per hr.	Lb. per hp. hr.	
	Hr.	Min.	Hr.	Min.					In.	Out.	In.	Out.						
Apr. 11, 1921	0	[1] 30	0	30	1,689	708	41	29.44	164	171	112	139	73	2.0	10.9	366.0	0.517	10.8
	1	00	0	30	1,637	644	42	29.44	164	170	110	137	76	2.8	9.8	320.0	.497	9.8
	2	00	1	00	1,633	639	43	29.46	164	170	114	138	77	2.5	10.9	321.7	.509	8.7
	3	00	1	00	1,644	652	45	29.42	164	170	116	139	75	2.4	10.5	331.3	.508	8.3
	4	00	1	00	1,644	652	47	29.42	164	170	118	139	73	2.6	9.7	320.7	.492	7.7
	5	00	1	00	1,640	648	49	29.36	164	170	110	137	71	2.6	9.4	320.3	.494	6.8

No. 1 stop.—End of first 5-hour period.

Apr. 12, 1921	5	[1] 30	0	30	1,681	697	46	29.23	164	170	113	138	76	2.2	8.2	350.0	.502	6.2
	6	00	0	30	1,639	647	51	29.23	164	170	112	138	75	2.7	13.7	3[illegible]0.0	.526	7.4
	7	00	1	00	1,636	643	54	29.29	165	170	113	139	76	2.7	20.4	[2] 377.6	.588	7.3
	8	00	1	00	1,635	642	57	29.15	165	170	113	139	73	2.7	19.4	370.5	.577	7.4
	9	00	1	00	1,641	649	60	29.12	165	170	116	141	69	2.9	14.0	332.0	.510	7.2
	10	00	1	00	1,631	637	59	29.13	165	170	118	111	73	2.6	18.8	337.3	.530	7.9

No. 2 stop.—End of second 5-hour period. Spark plugs in No. 2L cylinder, inlet side; 3L cylinder, exhaust side, and 1R cylinder, exhaust side, had broken porcelains. The spark plug in No. 5L cylinder, exhaust side, was fouled. They were all replaced with new plugs.

Apr. 13, 1921	10	[1] 30	0	30	1,682	698	68	29.00	166	170	117	145	77	2.5	14.1	332.5	.477	10.6
	11	00	0	30	1,651	661	69	29.00	166	170	120	147	72	2.8	10.7	312.0	.472	8.4
	12	00	1	00	1,647	656	71	29.00	165	170	120	147	70	2.7	15.6	313.7	.478	8.5
	13	00	1	00	1,627	632	71	29.00	165	170	120	143	78	2.9	9.6	290.0	.459	9.1
	14	00	1	00	1,640	648	73	29.00	164	170	123	146	79	2.8	9.9	295.0	.455	8.7
	15	00	1	00	1,636	642	73	29.00	164	170	121	146	75	2.7	10.5	296.0	.461	8.9

No. 3 stop.—End of third 5-hour period.

[1] Full throttle.

[2] Gasoline drain leaked.

Apr. 14, 1921.	15	[1] 30	0	30	1,700	722	66	28.74	163	170	120	146	83	2.4	16.0	367.0	.508	10.6
	16	00	0	30	1,647	656	64	28.74	164	170	122	145	79	3.3	11.8	291.0	.444	7.6
	16	45	0	45	1,640	648	64	28.76	164	170	119	144	77	2.7	10.9	292.5	.452	8.9

No. 4 stop—Valve-spring collar failed, allowing front intake valve of No. 6R cylinder to drop in on the piston, breaking valve and damaging piston and cylinder. A new piston and cylinder complete were installed. The front outside intake valve spring of No. 5R cylinder was broken. It was replaced. All the valves in No. 5R cylinder were ground.

Apr. 18, 1921.	17	00	0	15	1,652	663	54	29.18	164	170	126	141	86	2.6	9.3	312.0	.471	10.8
	17	30	0	30	1,641	649	56	29.18	163	170	129	142	87	2.8	8.5	307.0	.473	8.6

No. 5 stop—Tachometer adapter drive-shaft key sheared. Replaced with new adapter.

Apr. 18, 1921.	18	00	0	30	1,632	638	56	29.18	164	171	121	133	68	2.9	8.7	293.0	.460	8.4
	19	00	1	00	1,634	640	58	29.18	163	170	127	140	71	2.8	9.0	298.0	.466	8.0
	20	00	1	00	1,632	638	57	29.16	164	170	128	140	68	2.7	10.9	307.0	.481	7.2

No. 6 stop—End of fourth five-hour period.

[1] Time for 11 pounds.

Daily log of run—Continued.

TABLE OF AVERAGE RESULTS—Continued.

Date.	Time. Total elapsed. Hr.	Min.	Duration this run. Hr.	Min.	R.P.M.	B.H.P. from curve.	Carb. air temp., °F.	Baro., in. hg.	Water. Temp., °F. In.	Out.	Oil. Temp., °F. In.	Out.	Oil. Press., lb. per sq. in.	Man. vac., in. hg.	Carb. vac., in. H_2O.	Fuel cons. Lb. per hr.	Fuel cons. Lb. per hp. hr.	Oil cons. (Lb. per hr.)
Apr. 19, 1921.	20	[1] 30	0	30	1,711	737	58	29.17	164	170	131	147	71	1.8	8.3	361.0	.490	9.2
	21	00	0	30	1,640	648	60	29.17	163	170	131	145	73	2.8	7.1	287.0	.443	7.6
	22	00	1	00	1,628	632	62	29.17	163	170	130	144	73	2.8	7.3	286.0	.453	7.9
	23	00	1	00	1,639	646	65	29.13	164	171	130	145	72	2.5	7.4	298.3	.462	7.7
	23	45	0	45	1,638	645	65	29.14	164	170	131	145	67	2.4	7.0	299.5	.465	7.4

No. 7 stop—Tachometer adapter drive-shaft key sheared. Replaced with new adapter.

Apr. 19, 1921.	24	00	0	15	1,632	638	68	29.14	164	171	127	143	69	2.5	5.0	292.0	.457	8.6
	25	00	1	00	1,638	645	67	29.12	163	170	131	145	68	2.4	5.0	298.3	.463	9.3

No. 8 stop—End of fifth 5-hour period. After running 4½ hours of this period a water leak was detected in the water jacket of No. 4R cylinder under the cam shaft.

Apr. 20, 1921.	25	[1] 30	0	30	1,709	734	71	29.00	163	170	125	148	71	1.5	9.2	362.0	.493	8.8
	26	00	0	30	1,643	651	72	29.00	163	170	132	151	72	2.5	7.2	290.0	.446	9.8
	27	00	1	00	1,634	640	72	29.00	164	170	133	150	72	2.5	7.1	290.3	.454	9.0
	28	00	1	00	1,639	646	70	29.12	163	170	135	149	70	2.5	7.3	294.3	.456	8.3
	28	30	0	30	1,641	649	71	28.95	163	170	133	150	71	2.6	7.5	292.5	.452	8.0

No. 9 stop—End of day.

Apr. 21, 1921	29	00	0	30	1,651	663	58	28.87	163	170	135	148	70	2.6	9.4	316.5	.477	11.0
	30	00	1	00	1,631	637	61	28.88	163	170	133	149	71	2.5	7.4	297.0	.466	8.1

No. 10 stop—End of sixth 5-hour period. Spark plugs in No. 3R cylinder replaced. Broken porcelains.

Apr. 21, 1921	30	[1] 30	0	30	1,686	704	63	28.88	163	170	128	147	68	1.9	7.1	364.5	.518	5.4
	31	00	0	30	1,633	640	65	28.88	163	170	133	150	68	2.5	5.4	285.0	.446	8.0
	32	00	1	00	1,635	641	66	28.88	163	170	133	150	67	2.5	5.2	292.3	.456	7.3
	33	00	1	00	1,632	639	66	28.87	164	171	133	150	66	2.5	4.8	292.0	.457	7.7
	34	00	1	00	1,637	644	67	28.86	163	170	128	150	70	2.5	4.7	294.7	.458	6.9
	35	00	1	00	1,638	645	68	28.88	164	170	135	152	68	2.4	4.8	301.7	.468	8.0

No. 11 stop—End of seventh 5-hour period. After this run all the valves in Nos. 4R, 5R, 6R, and 6L cylinders were ground. One broken exhaust valve spring (outside) in No. 4R cylinder and one in No. 5R were replaced. One inlet valve spring in each of cylinders 1R, 4C, and 6R were broken. One intake valve guide in No. 6R was broken. Two exhaust valve guides in No. 5R cylinder were badly worn and were replaced, as were two intake valve guides in No. 6R and two exhaust valve guides in No. 6L cylinder. (See figures 12 and 13.) The water jackets under the cam shaft in No. 4R and No. 2L cylinders were welded. A new gasket was put under No. 6L cylinder. No. 6L rear exhaust valve was badly burnt. It was replaced. The left magneto was changed. It had an open circuit in the coil. One spark plug in each of the following cylinders had cracked porcelains: 1L, 2C, 4R, 5C, 5L, and 6R. All the plugs in No. 4L were oil soaked.

Apr. 27, 1921	35	[1] 30	0	30	1,653	664	62	29.00	160	170	116	143	71	1.9	6.5	242.5	[2] .365	8.2
	35	45	0	15	1,625	629	62	29.00	161	170	130	146	78	2.4	3.8	307.0	.488	8.0

No. 12 stop.—Air in gasoline line.

	36	00	0	15	1,613	616	62	29.00	162	171	121	142	63	2.7	4.7	288.0	.468	5.6
	37	00	1	00	1,611	612	65	28.99	161	170	129	146	66	2.7	4.0	283.0	.463	7.7
	38	00	1	00	1,612	613	65	28.99	162	170	131	147	71	2.7	3.8	284.3	.464	6.6

No. 13 stop.—End of day.

After this run several valve guides which were worn badly were replaced as follows: Rear exhaust valve guides No. 3R and No. 4L cylinders, rear inlet valve guide No. 5L and front exhaust valve guide in No. 6L cylinders (See fig. 12). All the outer springs on the right and left banks were replaced with standard Liberty exhaust springs. All the valves in Nos. 3R, 5R, 4L, 5L, and 6L cylinders were ground. One exhaust valve in No. 3R cylinder was badly burnt. It was replaced with a new valve. The front inlet valve tappets in Nos. 1R, 1L, 2L, 3L, 5L, and 6L cylinders were badly worn and replaced, as were both inlet tappets in Nos. 4L, 3R, and 6R cylinders and the rear inlet tappet in No. 5R cylinder (See fig. 14). All the tappet clearances on the right and left banks were reset.

Apr. 30, 1921	39	00	1	00	1,623	628	47	29.13	163	170	132	146	72	2.5	10.3	355.3	.566	7.8
	40	00	1	00	1,639	646	52	29.15	163	170	130	147	73	2.4	10.4	354.3	.549	7.6

No. 14 stop.—End of eighth 5-hour period.

[1] Full throttle.

Daily log of run—Continued.

TABLE OF AVERAGE RESULTS—Continued.

Date.	Time. Total elapsed. Hr.	Time. Total elapsed. Min.	Time. Duration this run. Hr.	Time. Duration this run. Min.	R.P.M.	B.H.P. from curve.	Carb. air temp., °F.	Baro., in. hg.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. In.	Oil. Temp., °F. Out.	Oil. Press., lb. per sq. in.	Man. vac., in. hg.	Carb. vac., in. H_2O.	Fuel cons. Lb. per hr.	Fuel cons. Lb. per hp. hr.	Oil cons. (Lb. per hr.)
May 2, 1921	40	[1] 15	0	15	1,680	696	43	....	162	171	133	145	66	1.9	3.0	346.0	.497	4.

No. 15 stop.—Water leak at weld between cylinder head and barrel of No. 1C cylinder. (See fig. 16.) The cylinder was replaced with a new one. The front intake valve guide in No. 4R and both intake valve guides in No. 5R cylinders were badly worn and replaced. (See fig. 12.) The following outer valve springs were broken: No. 3R (front exhaust) 5L (rear intake), 6R (rear exhaust), 5R (both intake). Nos. 4R and 5R exhaust valves were burnt. They were replaced. One cylinder stud between 5R and 6R cylinders was broken.

May 3, 1921. An attempt was made to complete the run, but after running a few minutes a stop was made because of fouled spark plugs in Nos. 4L, 5L, and 6L cylinders. The plugs were replaced and the engine again started. While warming up the engine No. 4L rear intake valve spring retaining collar failed. The valve and spring retaining collar were replaced.

Date.	Total Hr.	Total Min.	Dur. Hr.	Dur. Min.	R.P.M.	B.H.P.	Carb. air temp.	Baro.	Water In	Water Out	Oil In	Oil Out	Press.	Man. vac.	Carb. vac.	Lb. per hr.	Lb. per hp. hr.	Oil cons.
May 4, 1921	40	[1] 45	0	30	1,696	717	60	28.97	164	170	124	144	60	2.0	6.2	386.0	.538	10.0
	41	00	0	15	1,659	670	59	28.97	164	170	132	149	62	2.4	4.8	....	....	8.8

No. 16 stop.—Power decreased and speed fell off about 150 revolutions per minute. It was found that the small venturi tube bracket of the front left carburetor was broken. The main discharge nozzle was distorted. The spark plug-porcelains in Nos. 1R (two plugs), 5L (rear), 5R, 1L, 3L, and 5C (front) were cracked. The three spark plugs in 5C were fouled. The breaker point on the center magneto breaker arm was loose. It was replaced with a new breaker.

Date.	Total Hr.	Total Min.	Dur. Hr.	Dur. Min.	R.P.M.	B.H.P.	Carb. air temp.	Baro.	Water In	Water Out	Oil In	Oil Out	Press.	Man. vac.	Carb. vac.	Lb. per hr.	Lb. per hp. hr.	Oil cons.
May 5, 1921.	41	[3] 30	0	30	1,635	641	71	28.95	164	170	135	155	70	2.5	2.0	284.5	.444	7.2

No. 17 stop.—Small venturi tube bracket of front left carburetor failed.

Date.	Total Hr.	Total Min.	Dur. Hr.	Dur. Min.	R.P.M.	B.H.P.	Carb. air temp.	Baro.	Water In	Water Out	Oil In	Oil Out	Press.	Man. vac.	Carb. vac.	Lb. per hr.	Lb. per hp. hr.	Oil cons.
May 6, 1921.	42	30	1	00	1,634	640	65	29.01	164	169	131	151	71	2.4	4.5	318.7	.498	9.3
	43	30	1	00	1,620	624	69	29.01	164	170	133	152	70	2.4	3.0	300.7	.482	7.7
	44	30	1	00	1,623	627	70	29.00	163	169	138	154	73	2.3	2.3	296.3	.473	10.3
	44	45	0	15	1,605	605	72	29.00	163	169	138	155	70	2.2	3.0	278.0	.460	......

No. 18 stop.—At this time the engine began to weave badly. An external examination showed that the crank case was so badly cracked that further running was impossible.

AVERAGE OF AVERAGES OF FULL THROTTLE RUNS.

	R.P.M.	B.H.P.	Carb. air temp.	Baro.	Water In	Water Out	Oil In	Oil Out	Press.	Man. vac.	Carb. vac.	Lb. per hr.	Lb. per hp. hr.	Oil cons.
	1,689	708	58	29.05	163	170	122	144	72	2.0	9.0	347.8	.505	8.4

AVERAGE OF AVERAGES OF RUNS AT PARTIAL THROTTLE.

	R.P.M.	B.H.P.	Carb. air temp.	Baro.	Water In	Water Out	Oil In	Oil Out	Press.	Man. vac.	Carb. vac.	Lb. per hr.	Lb. per hp. hr.	Oil cons.
	1,635	642	62	29.06	164	170	126	145	72	2.6	8.4	306.8	.479	8.2

[1] Full throttle.
[2] Error in reading gasoline scales.
[3] Water leaked in No. 2R cylinder water jacket under cam-shaft housing.

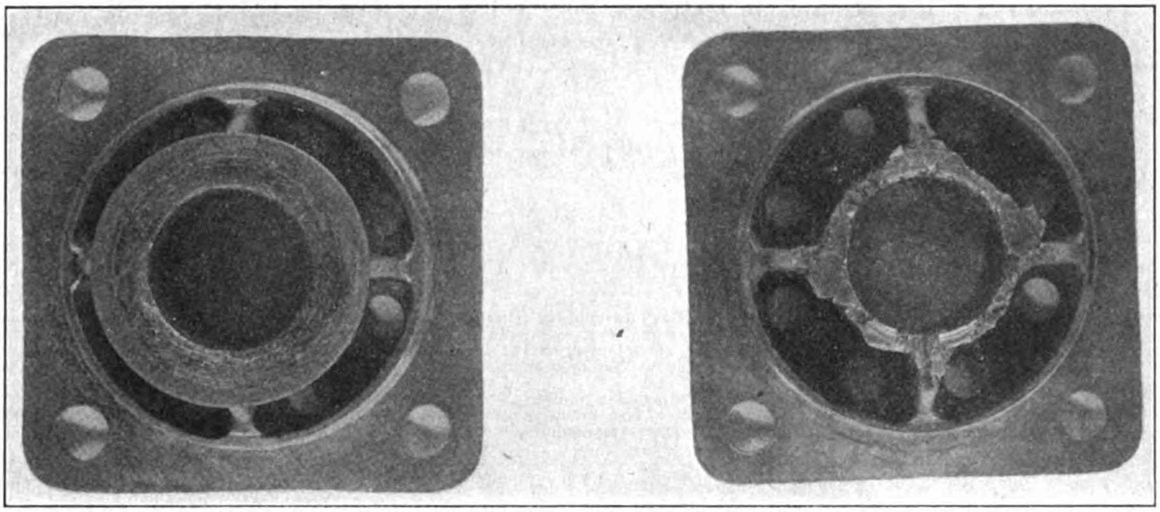


FIG. 7.—Camshaft drive-shaft lower bearings (upper) after preliminary runs on dynamometer.

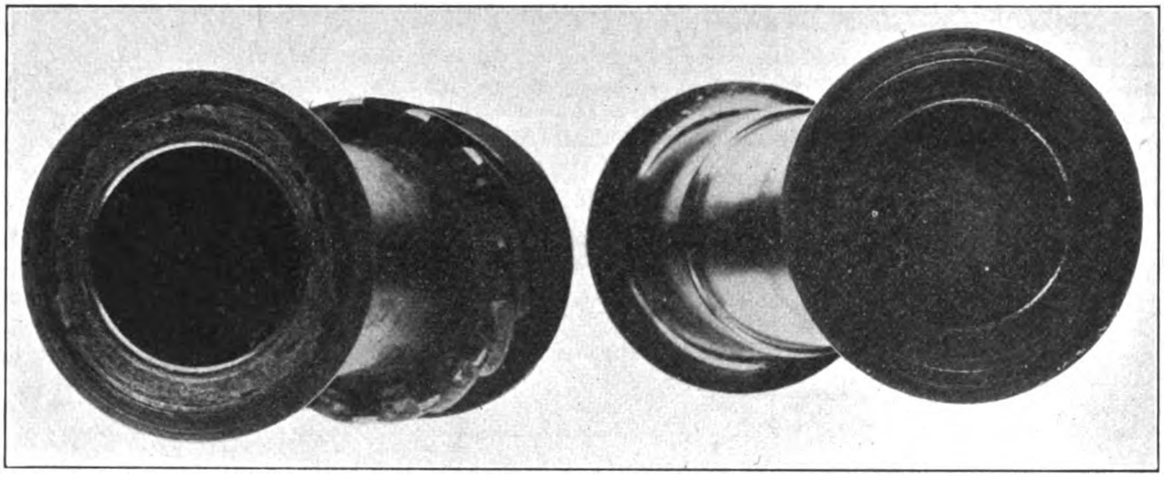


FIG. 8.—Lower center and lower side driveshaft spacing sleeves after preliminary runs on the dynamometer.

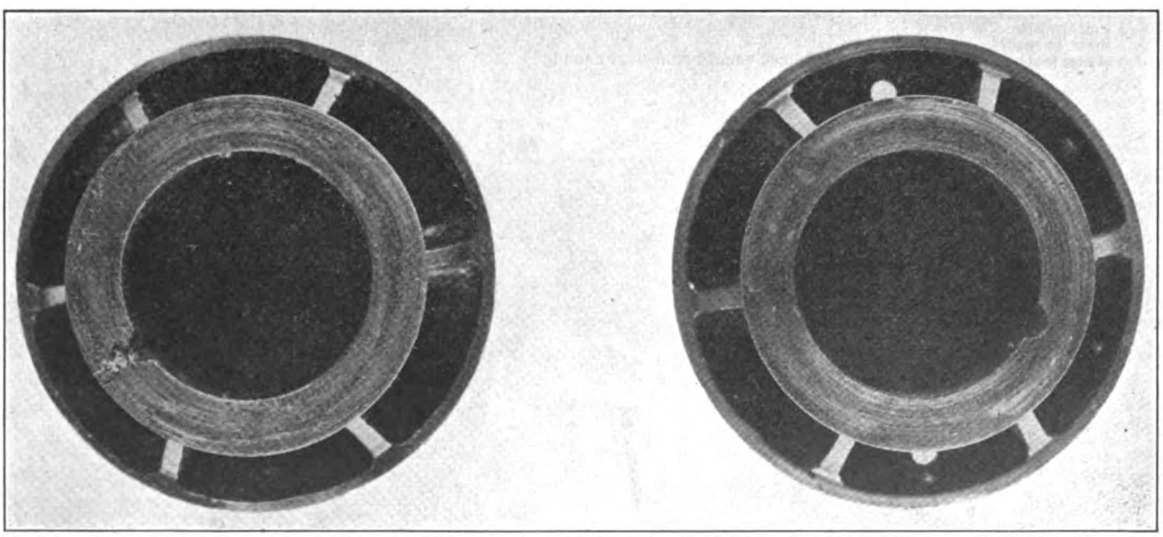


FIG. 9.—Camshaft drive-shaft bearings (lower) after preliminary runs on dynamometer.

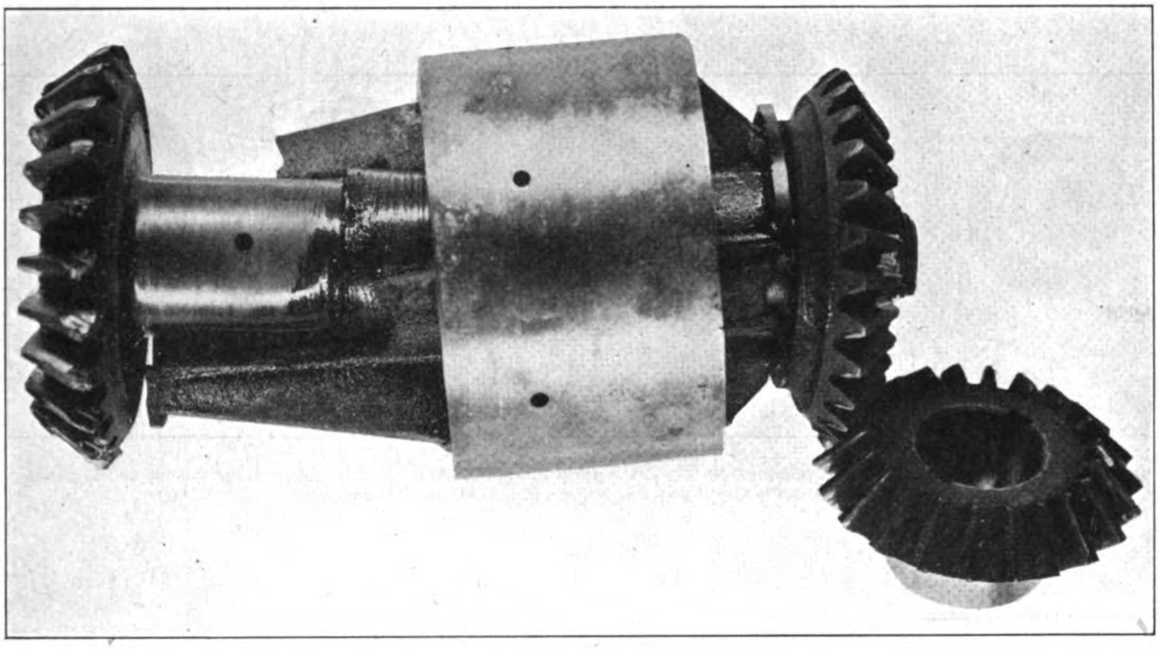


FIG. 10.—Burnt bearings oil and water pump gear assembly. This failure occurred during the preliminary runs on the dynamometer.

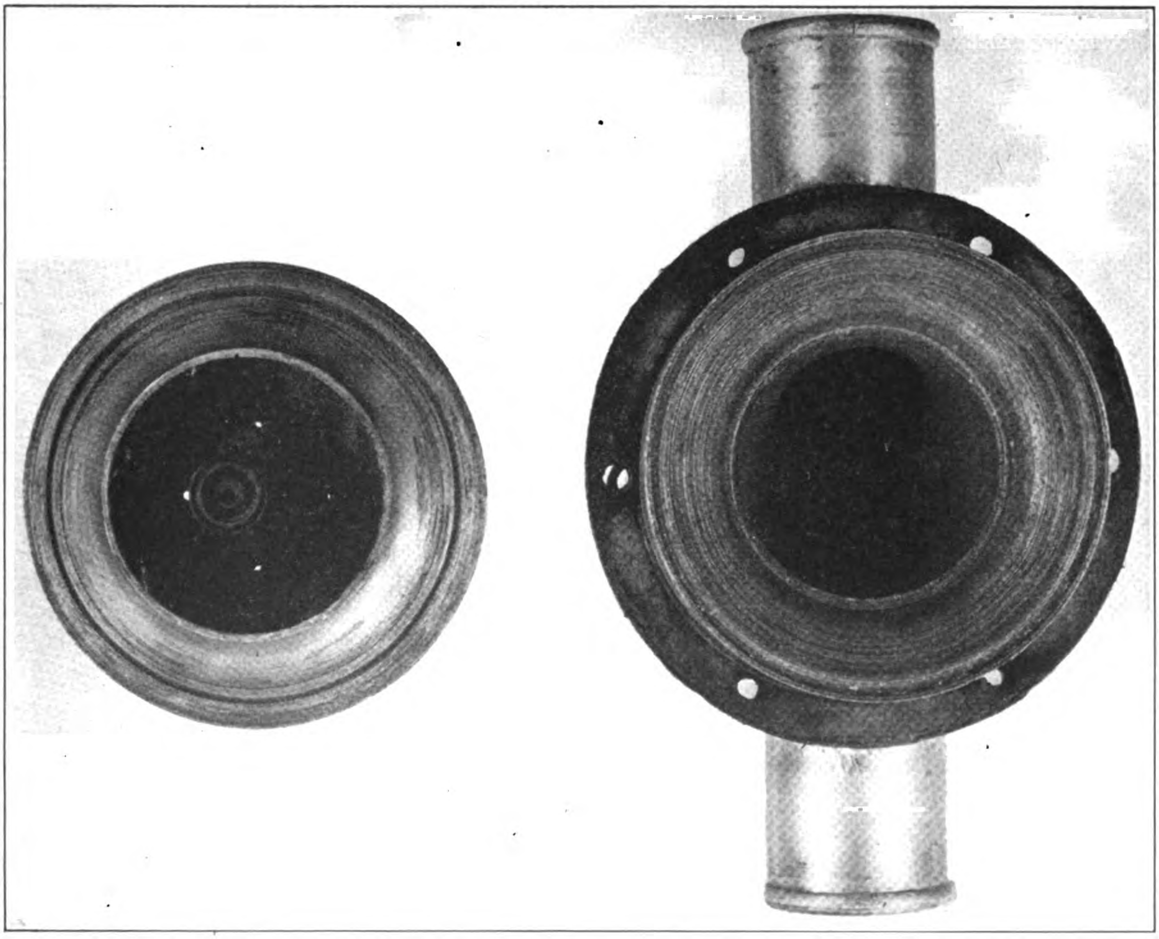


FIG. 11.—Water pump showing wear on impeller and lower casing. The wear developed during the dynamometer runs, but the pump was used during the torque stand after lignum vitae was substituted for the bronze button on the case.

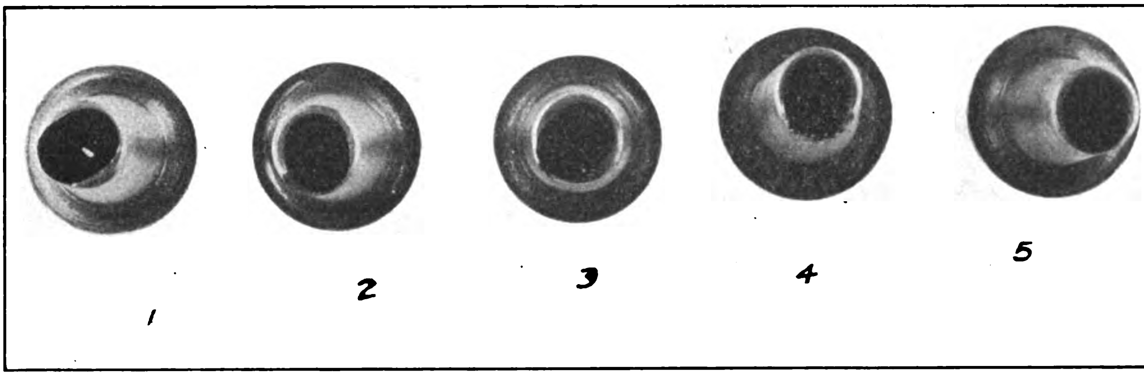


FIG. 12.—Worn valve guides after 35 hours running. No. 1 in this figure was removed April 28, 1921, after running 2 hours and 15 minutes. This is also typical of the valve guides replaced as indicated on page 17.

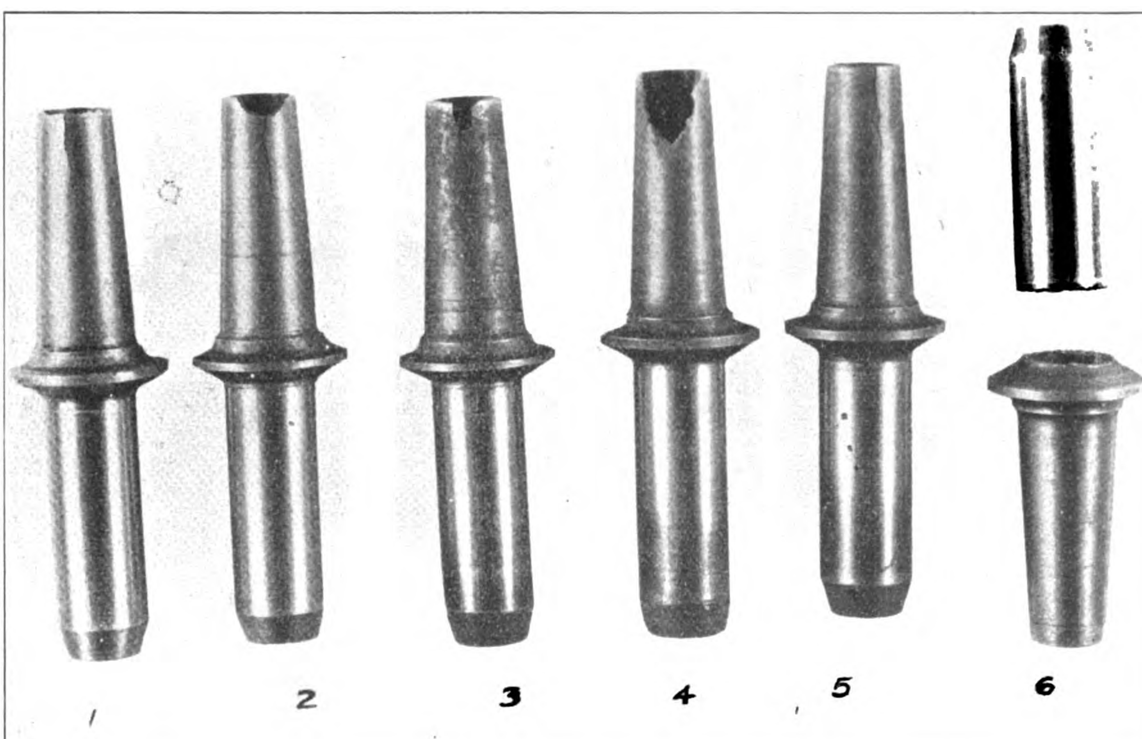


FIG. 13.—Worn valve guides after running 35 hours. No. 1 in this figure was removed April 28, 1921, after running 2 hours and 15 minutes. This is also typical of the valve guides replaced as indicated on page 17.

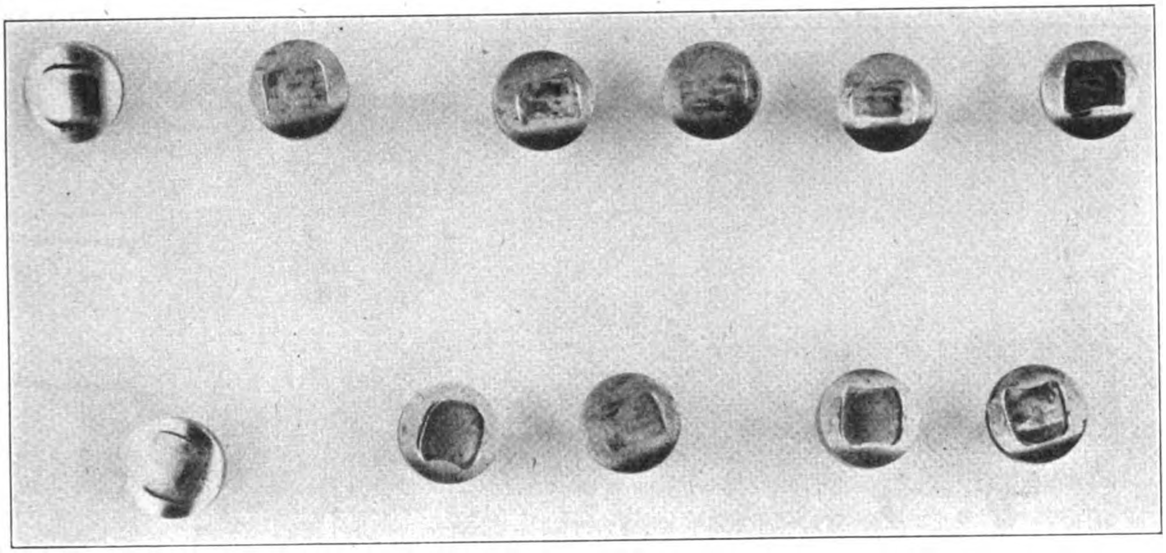


FIG. 14.—Worn valve tappets. These valve tappets were removed after running 38 hours.

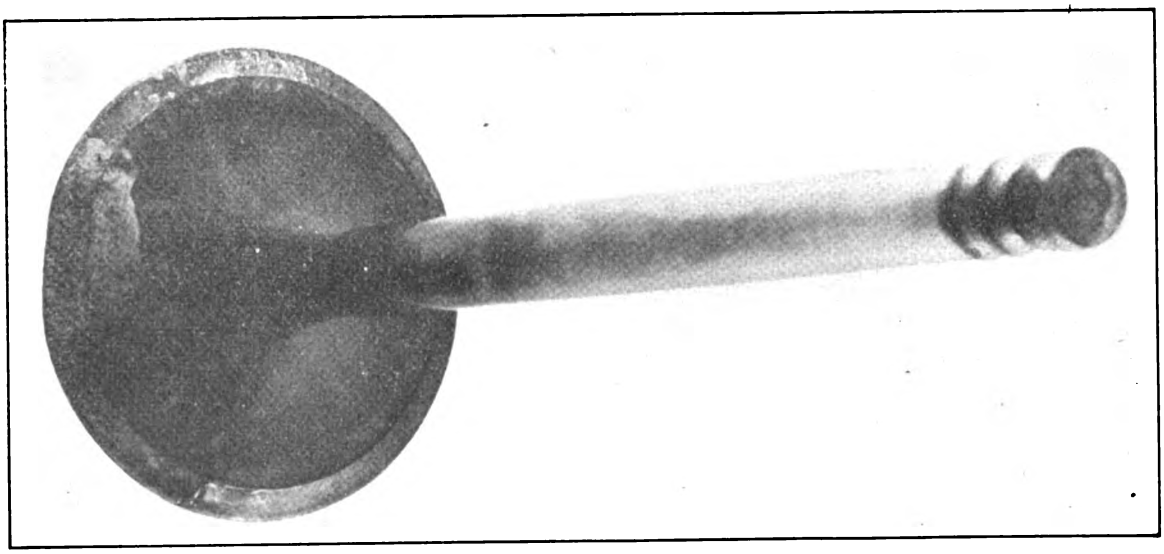


FIG. 15.—Burnt exhaust valve No. 6 L cylinder after running 38 hours.

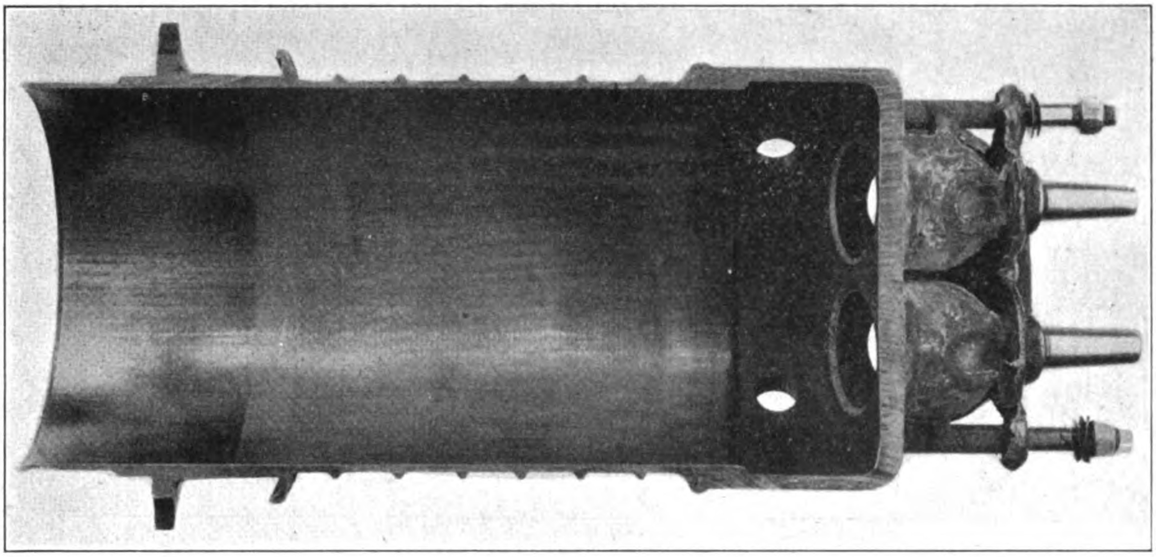


FIG. 16.—Sectional view of cylinder. A water leak developed in this cylinder after 40 hours and 15 minutes running at the junction of the cylinder head and barrel. The crack in the cylinder weld is not shown in this figure.

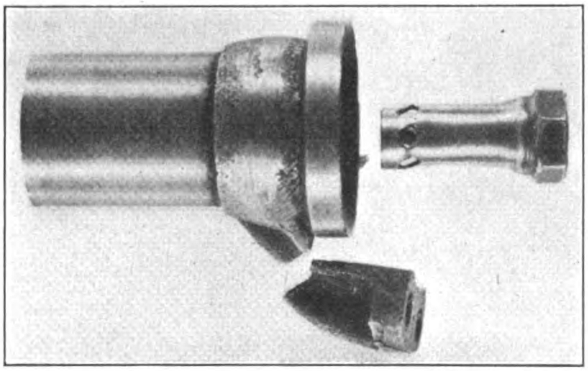
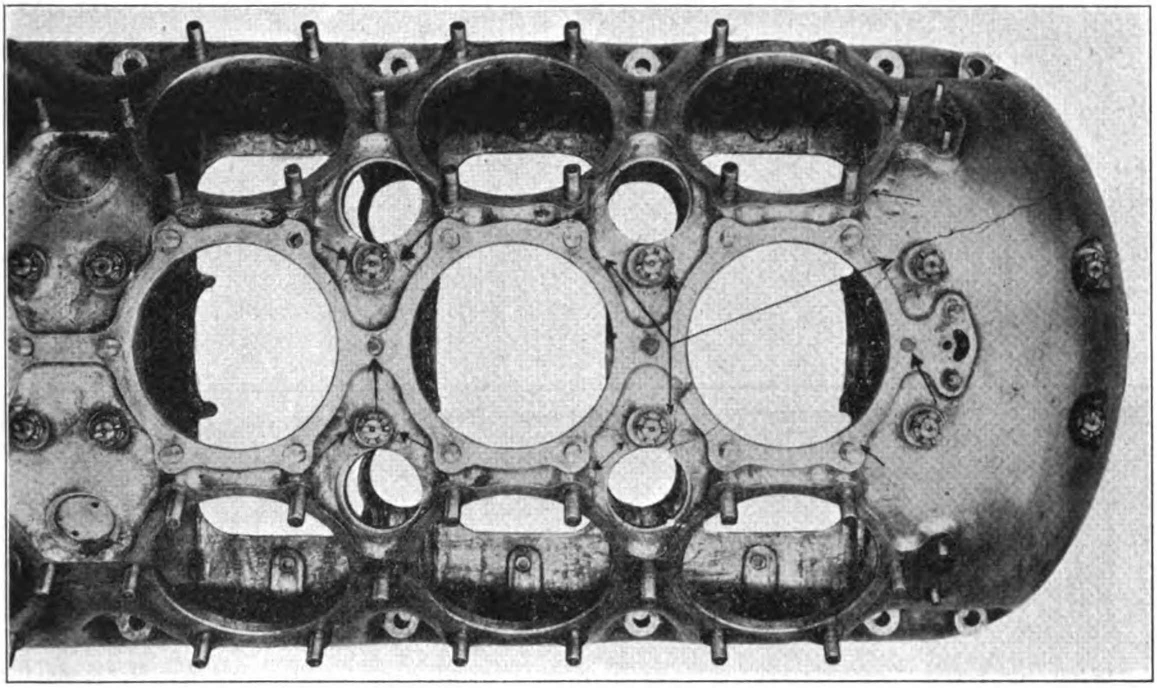


FIG. 17.—Typical failure of small venturi bracket and main discharge nozzle of front left carburetor. As indicated in the log of run two failures occurred during ninth five hour period.



Note fractures.

Fig. 18

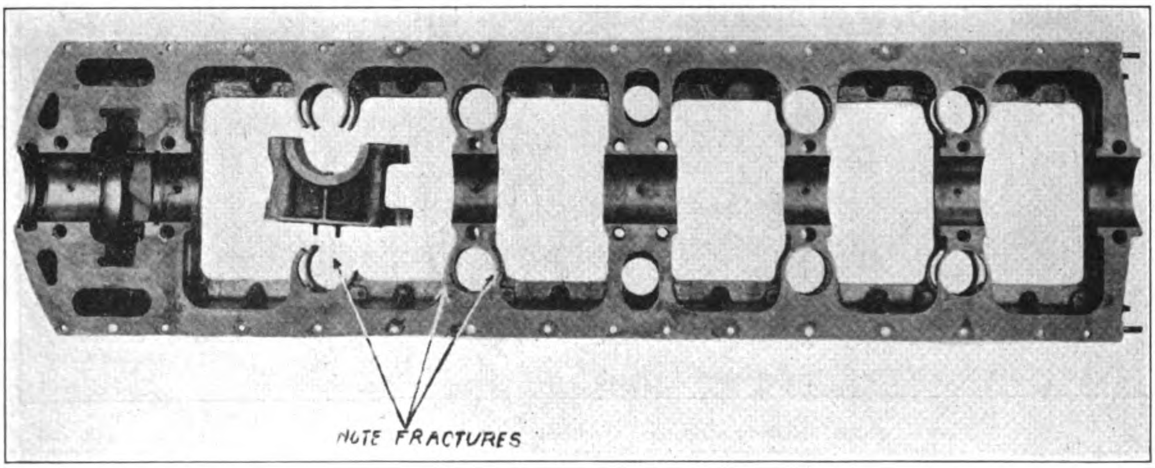


Fig. 19.—Lower crankcase after endurance run showing fractures.

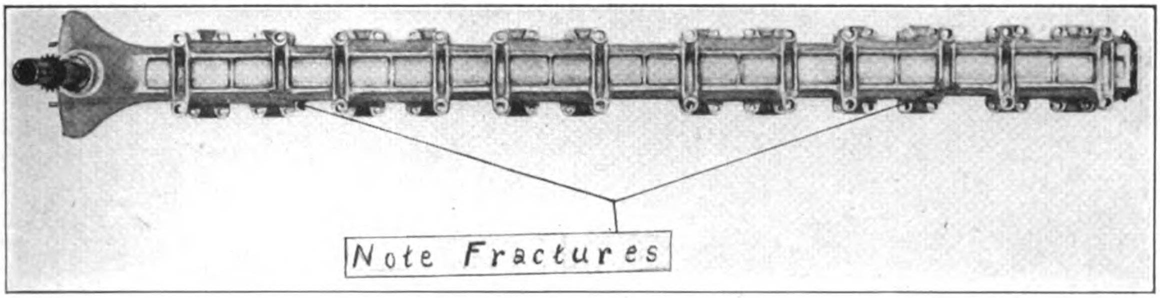


Fig. 20.—Camshaft housing showing typical fractures after endurance run. (Left bank.)

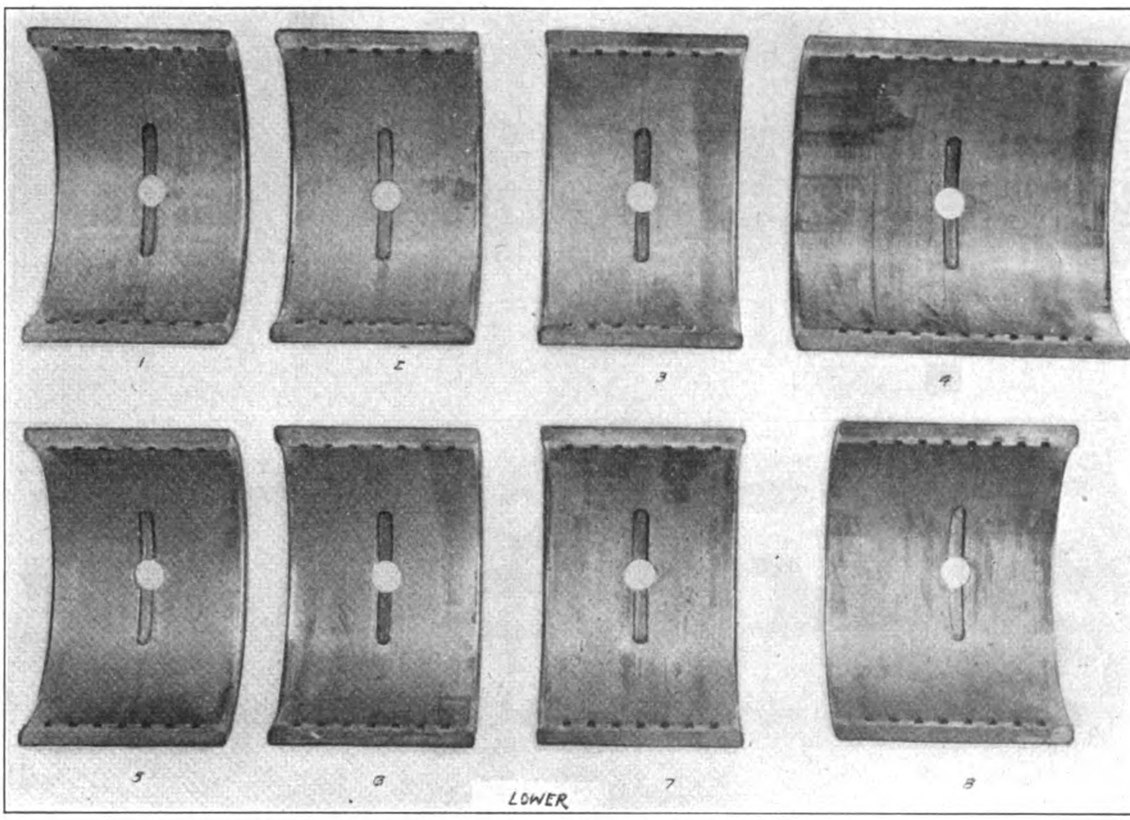


FIG. 21.—Lower main bearings. Condition after endurance run.

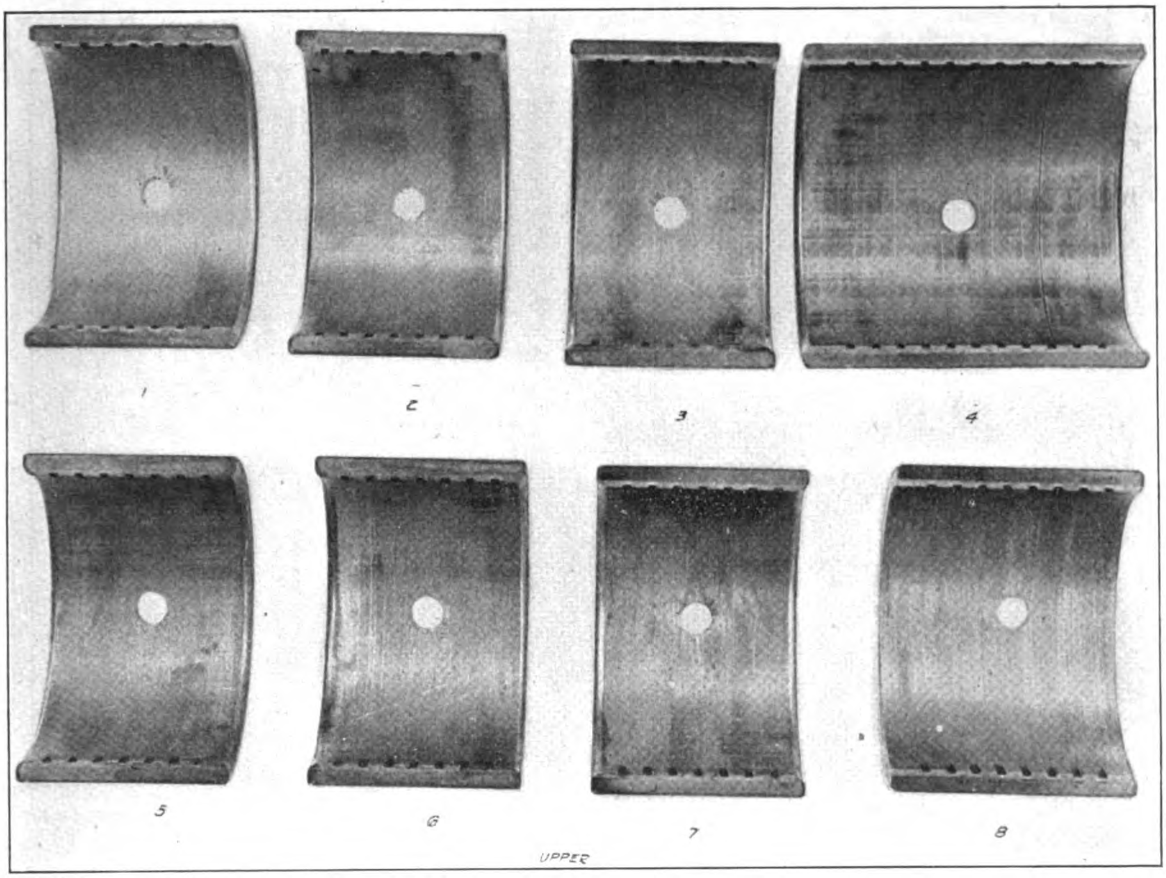


FIG. 22.—Upper main bearings. Condition after endurance run.

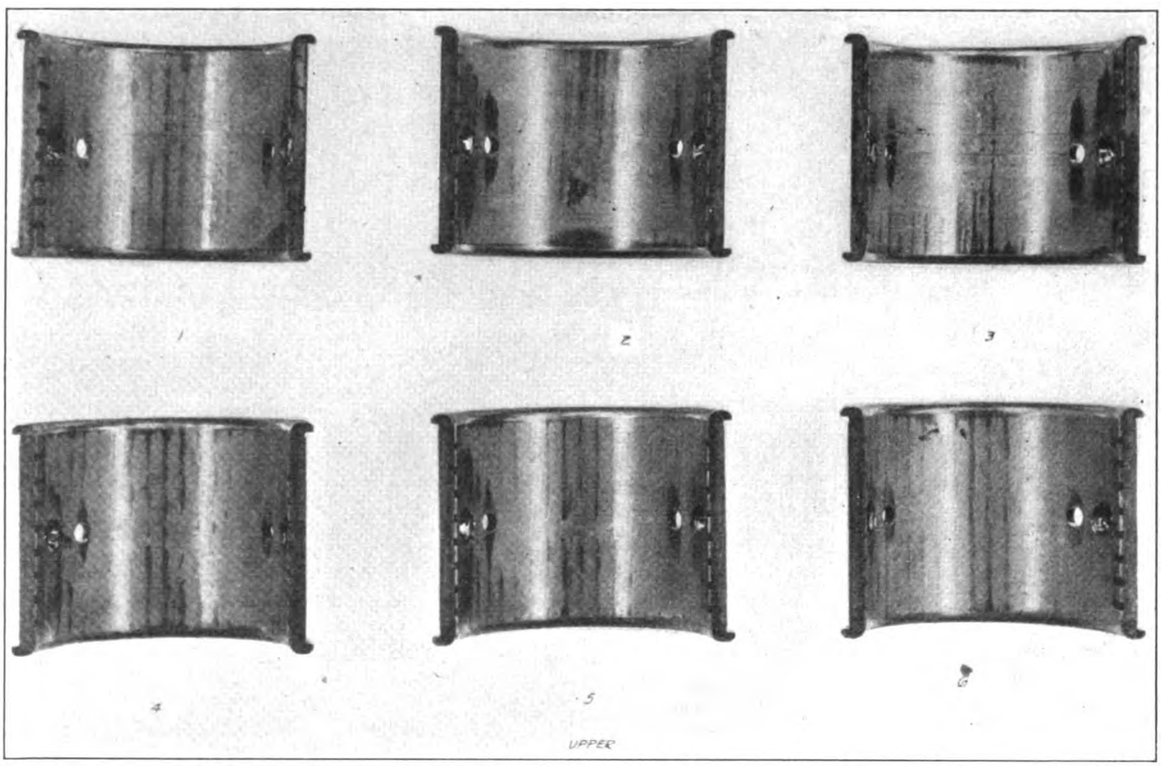


FIG. 23.—Upper connecting rod bearings after endurance run. Note original reamer marks made during assembly of engine.

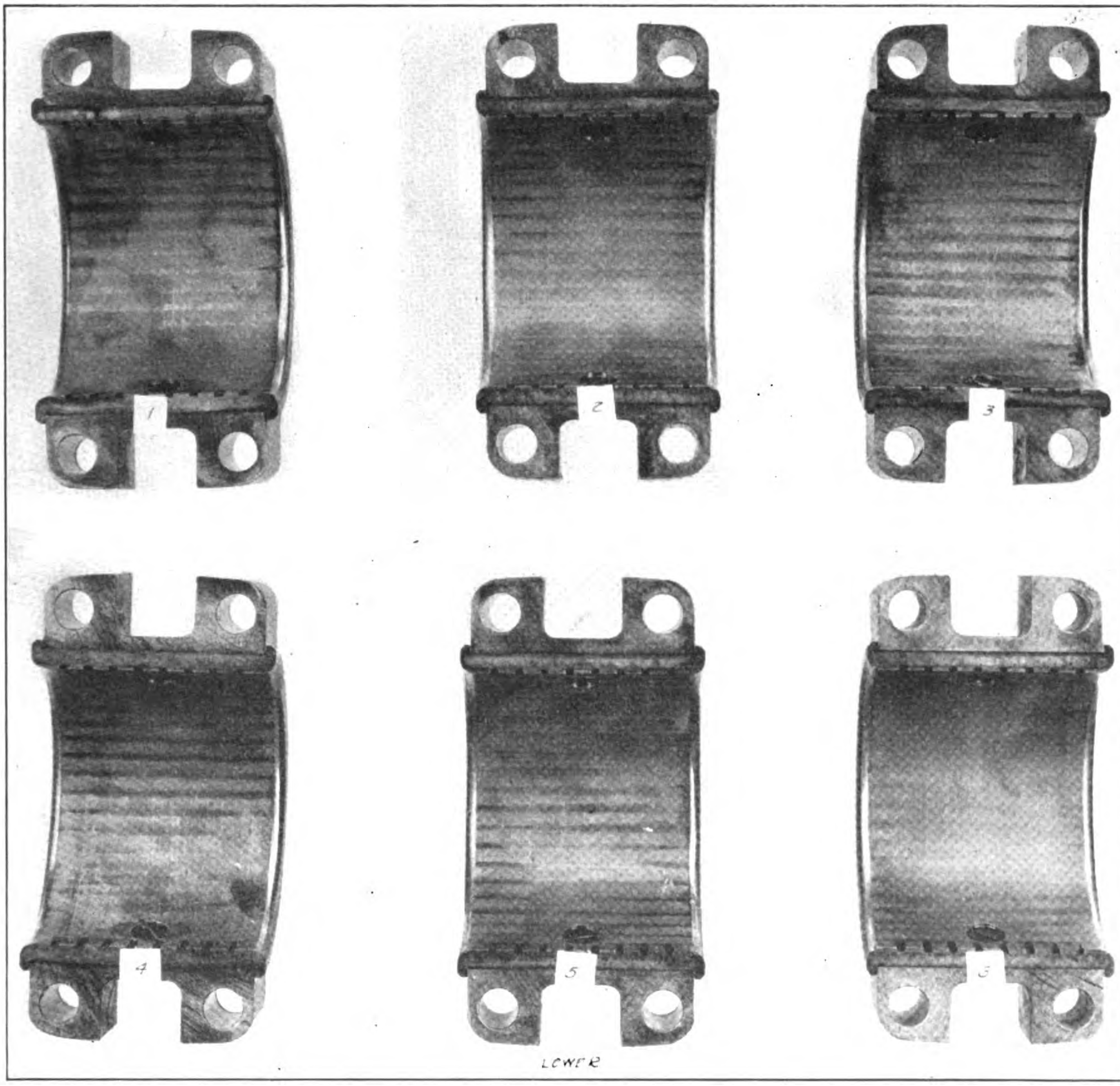


Fig. 24.—Lower connecting rod bearings after endurance run. Note original reamer marks made during assembly of engine.

FIG. 25.—Typical piston showing heavy carbon deposit.

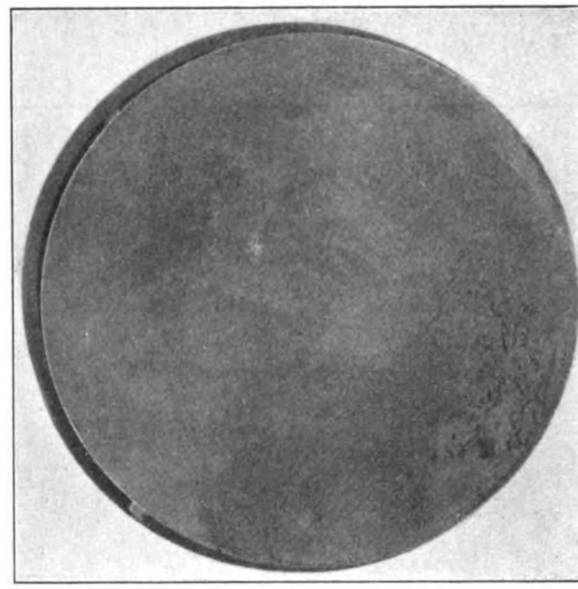


FIG. 26.—Typical piston showing average carbon deposit.

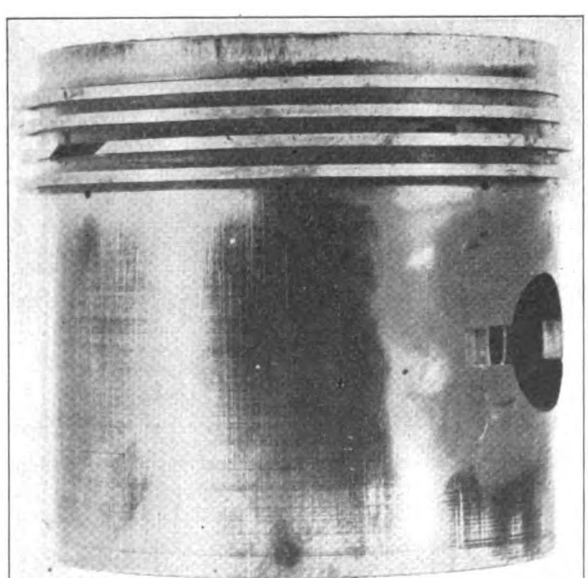


FIG. 27.—Typical piston showing wear on top land.

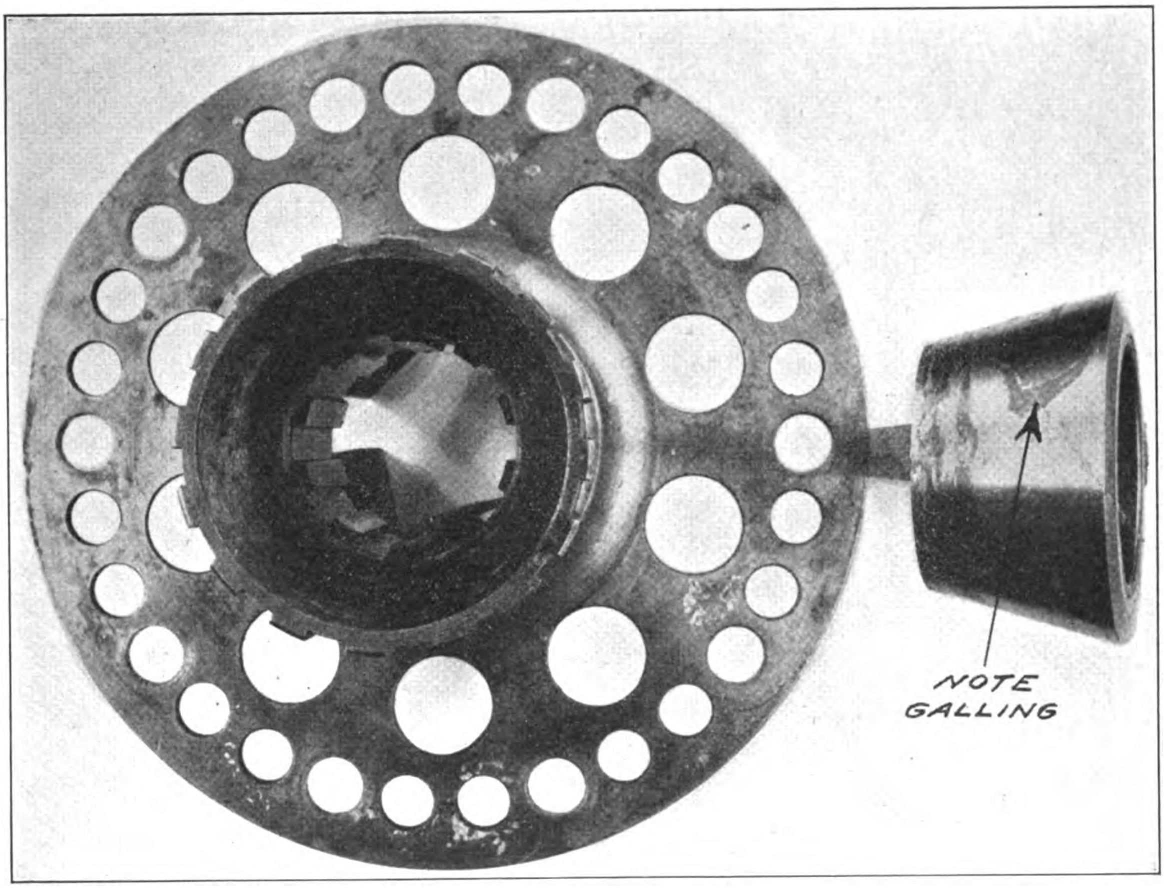


FIG. 28.—Propeller hub after endurance run.

FO[redacted]E ONLY

File D 52.1/371 — *McCOOK FIELD REPORT, SERIAL No. 1768*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 327

COMPARATIVE PERFORMANCE TEST OF X. B. I.-A EQUIPPED WITH HIGH COMPRESSION WRIGHT MODEL "H" AND PACKARD 1237 ENGINES

(PERFORMANCE TEST REPORT No. 67)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 11, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

COMPARATIVE PERFORMANCE TEST OF X. B. I.-A. EQUIPPED WITH HIGH COMPRESSION WRIGHT MODEL "H" AND PACKARD 1237 ENGINES.

OFFICIAL PERFORMANCE TEST—SUMMARY OF RESULTS.

August 11, 1921.

Airplane: X. B. I.-A.
No.: P-90.
Type: X.
Engine: Wright, model "H," high compression.
Propeller: X-24705.
Equipped as corps observation.
Weight empty (including water): 2,155 pounds.
Armament and equipment: 611 pounds.
Crew: 360 pounds.
Gasoline: [1] 598 pounds.
Oil: [1] 67 pounds.
Weight loaded: 3,791 pounds.
Weight per square foot: 935 pounds.
Weight per horsepower: 10.50 pounds (360 horsepower at 1,870 revolutions per minute).
Fineness: 108 Ae-9.8.

Standard altitude in feet.	Climb.			Speed.	
	Time in minutes.	R. p. m.	Rate feet per minute.	M. p. h.	R. p. m.
0	0	1,730	1,035	129.5	1,870
6,500	7.5	1,708	715	127.5	1,845
10,000	13.7	1,695	540	124.7	1,825
15,000	25.6	1,675	295	117.8	1,785
20,000	....	1,646	48	101.0	1,685
25,000	....	....	....	....	....
[1] 18,950	47.5	1,653	100	106.6	1,715
[2] 21,000	....	1,640	0	87.0	1,640

[1] Service ceiling. [2] Absolute ceiling.

Minimum speed at sea-level (lowest throttle): 62 m. p. h.
Landing speed: ———.

[1] Endurance, full throttle: ½ hour at ground and 4 hours at 10,000 feet.

August 11, 1921.

Airplane: X. B. I.-A.
No.: P-180.
Type: X.
Engine: Packard 1237.
Propeller: X-24705.
Equipped as corps observation.
Weight empty (including water): 2,305 pounds.
Armament and equipment: 611 pounds.
Crew: 360 pounds.
Gasoline: [1] 638 pounds.
Oil: [1] 74 pounds.
Weight loaded: 3,988 pounds.
Weight per square foot: 9.8 pounds (406 square feet).
Weight per horsepower: 11.4 pounds (350 horsepower at 1,900 revolutions per minute).
Fineness: 106 Ae–[2] 10.6.

Standard altitude in feet.	Climb.			Speed.	
	Time in minutes.	R. p. m.	Rate feet per minute.	M. p. h.	R. p. m.
0	....	1,760	940	125.0	1,900
6,500	8.5	1,727	610	121.5	1,850
10,000	15.3	1,708	434	118.0	1,810
15,000	32.8	1,680	180	109.5	1,740
20,000	....	....	....	....	....
25,000	....	....	....	....	....
[1] 16,550	44.3	1,670	100	104.5	1,710
[2] 18,500	....	1,655	0	89	1,655

[1] Service ceiling. [2] Absolute ceiling.

Minimum speed at sea level (lowest throttle): 66 m. p. h.
Landing speed: ———.

[1] Endurance, full throttle: ½ hour at ground and 4 hours at 10,000 feet.
[2] P-180 has a larger radiator than P-90.

90773—22

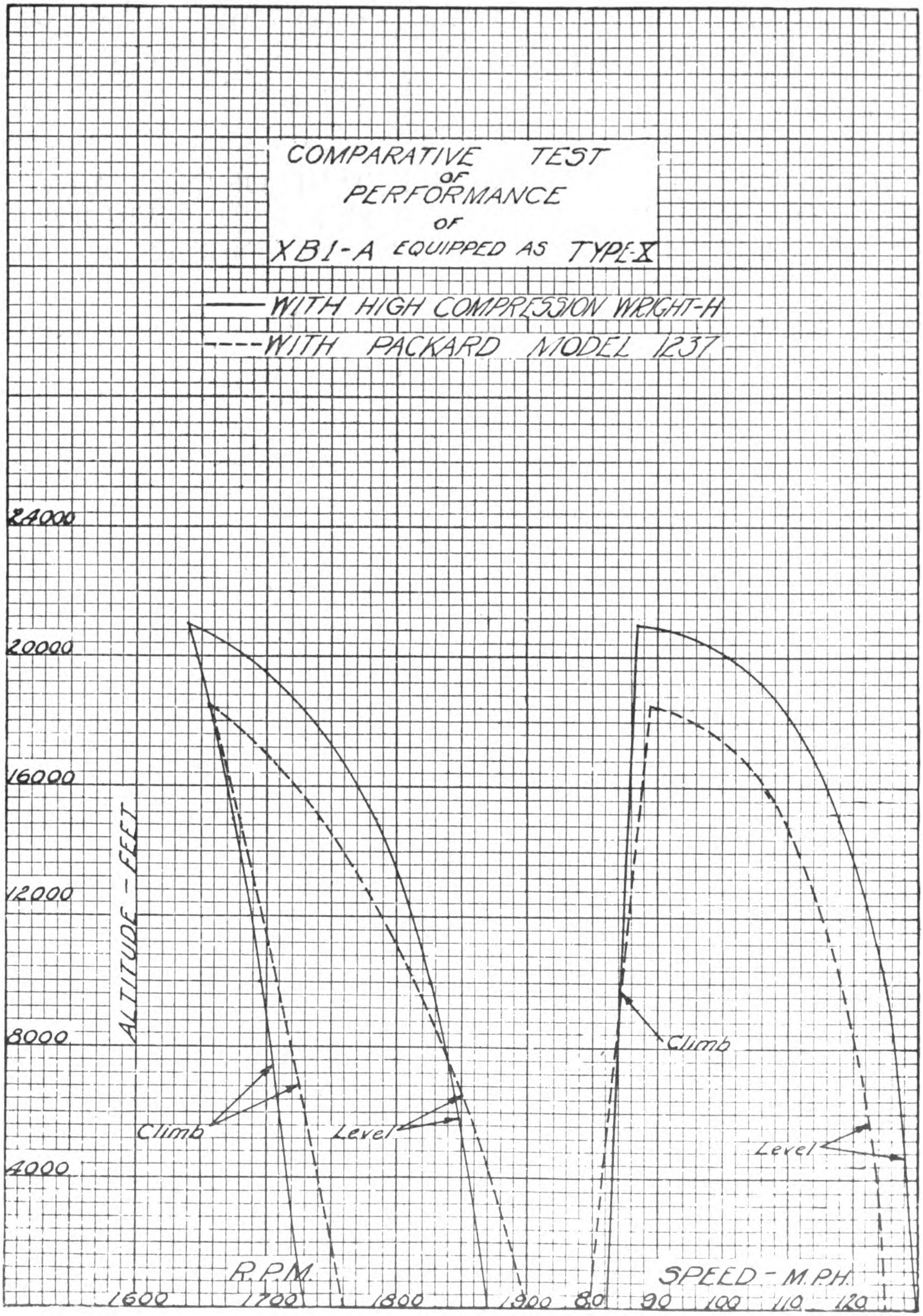
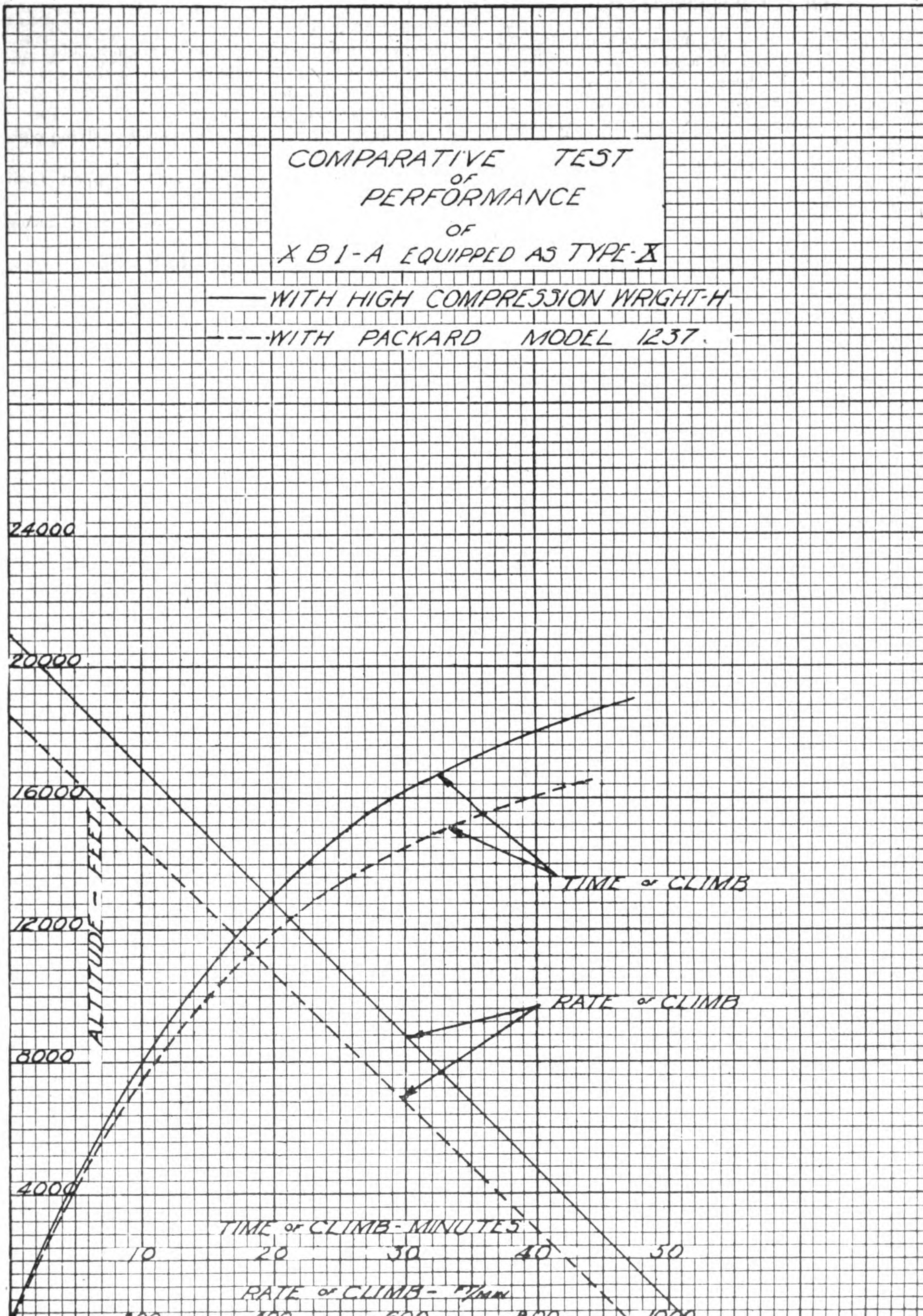

COMPARATIVE TEST
OF
PERFORMANCE
OF
XB1-A EQUIPPED AS TYPE-X
WITH HIGH COMPRESSION WRIGHT-H
WITH PACKARD MODEL 1237
24000
20000
16000
12000
8000
4000
ALTITUDE - FEET
Climb
Level
Climb
Level
R.P.M.
SPEED - M.P.H.
1600
1700
1800
1900
80
90
100
110
120

Fig. 1.



COMPARATIVE TEST of PERFORMANCE of XB1-A EQUIPPED AS TYPE-X
WITH HIGH COMPRESSION WRIGHT-H
WITH PACKARD MODEL 1237
24000
20000
16000
12000
8000
4000
ALTITUDE - FEET
TIME of CLIMB
RATE of CLIMB
TIME of CLIMB - MINUTES
10
20
30
40
50
RATE of CLIMB - FT/MIN
200
400
600
800
1000

FIG. 2.

PILOTS' OBSERVATIONS.

The comparative tests conducted between the high compression Wright and Packard engines installed in type X, X. B. I.-A airplanes, demonstrated that owing to the lighter weight per horsepower and lower fuel consumption the airplane equipped with the Wright engine gave the better performance.

The test was conducted with a full military load, the longitudinal balance being corrected by use of the adjustable stabilizer. Antiknock compound No. 1 was used in both engines during the test to prevent preignition. This fuel stains, leaves a gummy residue, and the exhaust fumes are rather disagreeable to the pilot.

The Packard engine operates with little vibration, has a quick acceleration, and cools well during climb, but could be operated with a smaller radiator, which would improve the performance. Approximately 100 revolutions per minute were lost during the climb, and when attempting to increase the revolutions per minute the altitude control was found to be so sensitive that there was danger of cutting the engine.

The Wright engine has an efficient altitude control, good acceleration, cools well, and shows a loss of 70 revolutions per minute in climb. The engine is steady at high speed, but has considerable vibration at low revolution per minute. A great improvement was noticeable in the performance of this engine as compared with the low-compression Wright 300.

No trouble of a serious nature was encountered with either engine during the test, but the endurance has not been determined.

O. G. Kelly,
First Lieutenant, A. S., Test Pilot.
Louis G. Meister,
Test Pilot.

DISTRIBUTION OF WEIGHTS.

X. B. I.-A, P-90.

(By pounds.)

Weight empty (with water): 2,155
Armament and equipment: 611.
Crew: 360.
Gasoline: 598.
Oil: 67.
Weight loaded: 3,791.
Weight on front wheels (tail skid on ground): 3,396.
Weight on tail skid (tail skid on ground): 395.
Weight on front wheels (flying position): 3,591.
Weight on tail skid (flying position): 200.
Center of gravity (distance from wheels in flying position): 10.8 inches.
Distance center line of wheels to point of support of tail skid: 200 inches.
Provisions for special equipment not carried during test.

X. B. I.-A, P-180.

(By pounds.)

Weight empty (with water): 2,305.
Armament and equipment: 611.
Crew: 360.
Gasoline: 638.
Oil: 74.
Weight loaded: 3,988.
Weight on front wheels (tail skid on ground): 3,515.
Weight on tail skid (tail skid on ground): 473.
Weight on front wheels (flying position): 3,732.
Weight on tail skid (flying position): 256.
Center of gravity (distance from wheels in flying position): 13.1 inches.
Distance center line of wheels to point of support of tail skid: 200 inches.
Provisions for special equipment not carried during test.

DESCRIPTION OF AIRPLANE.

DIMENSIONS.

Over-all span: 39 feet $4\frac{9}{16}$ inches.
Over-all length: 25 feet 6 inches.
Over-all height: 9 feet $9\frac{1}{2}$ inches.
Height at hub of propellor above ground:
In flying position: 5 feet $7\frac{1}{8}$inches.
At rest: ———.

AIRPLANES.

Wing curve: R. A. F., 15.
Sweep back: None.
Dihedral: 3° 30′.
Stagger: 1 foot 6 inches.
Total area, including ailerons: 405.6 square feet.
Gap: 5 feet 5 inches.

UPPER PLANE.

(Including center section.)

Span: 39 feet $4\frac{9}{16}$ inches.
Chord: 5 feet 6 inches.
Area, with ailerons: 202 square feet.
Incidence: 2°.

LOWER PLANE.

Span: 39 feet $4\frac{9}{16}$ inches.
Chord: 5 feet 6 inches.
Area: 202 square feet.
Incidence: 1° 45′.

AILERONS OR FLAPS.

Number: 4.
Arrangement: 2 upper; 2 lower.
Upper length: 7 feet $1\frac{13}{16}$ inches.
Upper chord: 1 foot $11\frac{9}{16}$ inches.
Upper area: 13 square feet.
Lower length: 7 feet $1\frac{13}{16}$ inches.
Lower chord: 1 foot $11\frac{9}{16}$ inches.
Lower area: 13 square feet.
Total area: 26 square feet.
Distance from center of ailerons to longitudinal axis of airplane: 16 feet $\frac{1}{2}$ inch.

CENTER SECTION.

(Upper.)

Area: 4 feet $3\frac{3}{16}$ inches.
Dimensions: 4 feet $\frac{1}{2}$ inch.
Contents: Gravity gas tank.

STABILIZER.

Area: 22.5 square feet.
Setting: Adjustable.

ELEVATOR.

Area: 23 square feet.
Distance from leading edge of elevator to center of gravity of airplane: 16 feet 11 inches.

RUDDER.

Area: 4 feet $2\frac{3}{8}$ inches.
Distance from leading edge of rudder to center of gravity of airplane: 16 feet 8 inches.

FUSELAGE.

Maximum cross-section shape: 3 feet $5\frac{1}{2}$ inches.
Maximum cross-section area: ———.
Maximum cross-section dimension: 2 feet 8 inches.
Distance of maximum section from leading edge, lower plane: ———.

LANDING GEAR.

Number of wheels: 2.
Tread: 5 feet 6 inches.
Shock absorbing system: rubber cord.
Braking device: Tail skid.
Wheels ahead of center of gravity: 1 foot $3\frac{3}{8}$ inches.

FIN.

Area: 10.3 square feet.

DESCRIPTION OF POWER PLANT.

ENGINE.

Make: Packard.
Factory No.: ———.
A. S. No.: 94603.
Type: Vee–12 cylinder.
Number in plane: 1.
Location: Nose of fuselage.
Rated h. p.: 300.
Rated r. p. m.: 1,800.
Bore: 5-inch.
Stroke: $5\frac{1}{2}$-inch.
Compression ratio: 5/5 to 1.
Weight dry: 738 pounds.
Gas consumption: 0.515.
Oil consumption: 4.1 pints per b. h. p. hr.
Weight of water in engine: 39 pounds.
Remarks: ———.

IGNITION.

Battery of magneto: Magneto.
Make: Dixie.
Number: 2.
Advance: 26°.
Gas interrupter: 0.020.
Distributor: Carbon brush contact.
Plugs, make: A. C.
Type: Metal body porcelain insulator.
Gap: 0.015.
Remarks: ———.

CARBURETORS..

Make: Zenith.
Type: Single Venturi Duplex Packard Zenith.
Number: 1.
Setting jet: 165.
Choke: 31 m. m.
Compensator: ———.
Gas drains: 1.
Air intake: Led into slip stream, below fuselage.
Mixture control: Standard.
Effect to altitude: ———.
Remarks: ———.

RADIATORS.

Make: ———.
Type: Honeycomb.
Number: 1.
Position: Nose of fuselage.
Frontal area: 4.8 square feet.
Depth: 5 inches.
Length: 41 inches.
Width: 28 feet.
Radiator surface: 235 square feet.
Temperature adjustment: Shutters.
Water capacity: 64 pounds.
Flow, gallons per minute: 68 at 33 pounds at 3.3 pounds per square foot.
Thermometers, make: ———.
Weight: 122 pounds.
Type: Cellular.
Water capacity of whole system: 108 pounds.

EXHAUST PIPES.

Description: Short individual stacks to each cylinder, leading to manifold extending to rear as far as front cockpit.

LUBRICATION.

Capacity oil tank: 23 quarts.
Dimensions oil tank: ———.
Oil used (brand): Liberty.
Oil pressure: 60.
Oil temperature: ———.
Type pump: Gear.
Wet or dry sump: Dry sump.
If wet, capacity: ———.
Description lubrication system: Standard. Pump forces oil to main bearings, cam shafts, and by splash to cylinder walls and wrist pins.

FUEL SYSTEM.

Number of tanks: 2.
Location: Main, to rear of engine; reserve, center section upper wing.
Capacity, main, pounds: 81 gallons, 486 pounds.
Capacity, reserve, pounds, ———.
Material: ———.
Gauge: ———.
Description of fuel-supply system: Standard X. B. I.–A system, using sylphon pump.

ENGINE CONTROL.

Description: Rod and lever.

PROPELLER.

Make: Engineering Division.
Number of blades: 2.
Diameter: 8 feet 8 inches.
Pitch: 6.41 feet.
Tips: Terneplate.
Clearance: ———.
Mfg. No.: ———.
A. S. No.: 109447.
Remarks: x–24705, 01202.

FIG. 3.

FIG. 4.

FIG. 5.

File D 52.338/31 *McCOOK FIELD REPORT, SERIAL No. 1769*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV March 15, 1922 No. 328

REPORT OF WIND TUNNEL TESTS ON AEROFOILS: DAYTON-WRIGHT NOS. TT-1 AND TT-2, DAYTON-WRIGHT NOS. 5 AND 6, AND GOTTINGEN NO. 387

(AIRPLANE SECTION, S. & A. BRANCH)

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
October 24, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT OF WIND TUNNEL TESTS ON AEROFOILS: DAYTON-WRIGHT NOS. TT-1 AND TT-2, DAYTON-WRIGHT NOS. 5 AND 6, AND GOTTINGEN NO. 387.

OBJECT OF TESTS.

The above aerofoils were tested at Massachusetts Institute of Technology during June and August, 1921, to determine lift, drag, L/D, center of pressure, and moments about the leading edge.

DESCRIPTION OF MODELS.

The Dayton-Wright Nos. 5 and 6 and the Gottingen No. 387 were constructed of wood by the Dayton-Wright Co. Their dimensions are 18 by 3 inches.

The Dayton-Wright aerofoils Nos. TT–1 and TT–2 have the same ordinates as the DW–3 and DW–4, respectively, but have a split trailing edge. Instead of a true flap wing the lower part of the trailing edge up to the rear spar is hinged and adjustable, while the upper part of the trailing edge remains rigid. The flap chord in each case is 30 per cent of the wing chord. These two variable camber sections have a span of 17.453 inches and a mean geometrical chord of 3.0356 inches, and were constructed of bakelite by the Dayton-Wright Co. They are tapered and the center line of the flap hinges is at right angles to the chord line. In testing these models, however, an actual flap was not used. On the lower trailing edge, triangular sections were built up in such a manner that the face of the sections made successive angles of 15°, 30°, and 45° to the wing chord.

RESULTS.

These sections are compared with the R. A. F. 15 and the U. S. A. 27. Figure 1 gives a comparison of the profiles of a number of sections.

The Dayton-Wright No. 5 has a maximum lift coefficient of 0.00265 compared to 0.00258 for the R. A. F. 15, 0.00365 for the U. S. A. 27, 0.00398 for the D. W. No. 6, 0.00307 for the D. W. TT–1, 0.00318 for the D. W. TT–2, the two latter values with the flap at 0°, and 0.00415 for the Gottingen No. 387. The lift coefficient for the TT–1 and TT–2 increases very rapidly for increasing angle of flap to chord. The maximum Ky for TT–1 with flaps at 45° being 0.00485 and for the TT–2 with flap at 45° being 0.00499. The D. W. No. 5 is better than the D. W. TT–1 or TT–2 for stability, but less stable than the R. A. F. 15 or the U. S. A. 27.

The maximum L/D for the D. W. No. 5 is 16.6, which is higher than the maximum L/D for any of the other sections, the L/D for the D. W. No. 6 being 13.63, 14.8 for the TT–1 with flap at 0°, 15.22 for the TT–2 with flap at 0°, 13.5 for the Gottingen 387, 16 for the U. S. A. 27 and 16.3 for R. A. F. 15.

The maximum L/D for the TT–1 and TT–2 falls very rapidly with increasing angle of the flap to the wing chord. Maximum L/D for the TT–1 with flap at 45° is 4.4 and for the TT–2 with flap at the same angle is 4.5. The minimum drag coefficient of the two sections increases very rapidly with increasing angle of the flap to the chord.

The criterion of high speed for pursuit airplane is the L/D taken at 1/9 maximum Ky. The L/D at this Ky for the D. W. No. 5 is 6.5 as compared with 4.5 for the Gottingen No. 387, 5.4 for the D. W. No. 6, a maximum of 5.65 for the D. W. TT–1, a maximum of 6.2 for the D. W. TT–2, 7.7 for the R. A. F. 15, and 4.6 for the U. S. A. 27. The D. W. No. 5 will therefore have a higher speed than any of the others except the R. A. F. 15. The L/D at this Ky falls very rapidly for the TT–1 and TT–2 as the flap angle is increased. For the TT–1 it is only 1 at 45° and 1.3 for the TT–2.

The criterion of high speed for reconnaissance airplanes is the L/D at $\frac{\text{Ky maximum}}{6.25}$. At this value of Ky the L/D for the D. W. No. 5 is 9.3 as compared to 7.85 for the D. W. No. 6, a maximum of 8.10 for the D. W. TT–1, a maximum of 8.9 for the D. W. TT–2, 6.75 for the Gottingen No. 387, 9.7 for the R. A. F. 15 and 7 for the U. S. A. 27. The D. W. No. 5 has a higher value of L/D than any of the others except the R. A. F. 15 at this Ky.

The criterion of high speed for large airplanes is the L/D at 1/4 maximum Ky. The L/D for the D. W. No. 5 at 1/4 maximum Ky is 12.85, as compared to 13.5 for R. A. F. 15, 11.7 for the U. S. A. 27, 10.45 for Gottingen No. 387, 11.4 for the D. W. No. 6, a maximum of 12.60 for the D. W. TT–1, and a maximum of 12.7 for the D. W. TT–2.

The speed range is expressed by the formula:

$$\frac{\sqrt{\text{Ky maximum}}}{\sqrt{\text{Kx minimum}}}$$

The speed range of the Dayton-Wright No. 5 is 1.446, for the R. A. F. 15 it is 1.494, for the U. S. A. 27 it is 1.410, for the Gottingen No. 387 it is 1.410, for the D. W. No. 6 it is 1.446, for the D. W. TT–1 it is a maximum at 1.488, and for the TT–2 it is a maximum at 1.445. The D. W. TT–1 has a larger speed range than any of the other aerofoils except the R. A. F. 15. The speed range for the D. W. TT–1 and TT–2 decreases rapidly with increase of angle of flap.

The ceiling and climb for constant loading is expressed by the maximum value of $Ky^{3/2}/Kx$. The value for the U. S. A. 27 is 0.665, for the R. A. F. 15 is 0.615, for the Gottingen No. 387, 0.623; for the D. W. No. 5, 0.629; for the D. W. No. 6, 0.604; a maximum of 0.610 for the D. W.

TT–1 and a maximum of 0.638 for the D. W. TT–2. The D. W. TT–2 is second only to the U. S. A. 27 for ceiling and climb. The ceiling and climb, however, drop off rapidly for the D. W. TT–1 and TT–2 with increase of flap angle.

The ceiling and climb with constant landing speed is determined from the minimum value of the expression

$$\sqrt{\frac{\frac{\text{Ky maximum}}{\text{Ky}}}{\text{L/D}}}$$

The L/D corresponds to the Ky to be used.

The value for the Gottingen No. 387 is 0.1035, for the D. W. No. 5, 0.0818; for the D. W. No. 6, 0.1045; for the R. A. F. 15, 0.0827; for the U. S. A. 27, 0.0908; for the D. W. TT–1 with flap at 0°, 0.0912 and for the D. W. TT–2 with flap at 0°, 0.0877. For increasing flap angles for these two variable sections this value decreases, the value with the flap at 45° for the TT–1 being 0.2360 and for the TT–2 at the same angle being 0.2310.

For the D. W. No. 5 and R. A. F. 15 the maximum forward position of the center of pressure is at 29 per cent of the chord, for the Gottingen No. 387 it is 32 per cent, for the D. W. No. 6 it is 30.3 per cent, for the D. W. TT–1 it is 35.1 per cent with flap at 0°, for the D. W. TT–2 it is 35.8 per cent with flap at 0°, and for the U. S. A. 27 it is 27.4 per cent. For the variable sections, D. W. TT–1 and TT–2, the maximum forward position has a maximum variation of about 10 per cent of the chord in each case with the flaps set at various angles from 0° to 45°, inclusive.

The center of pressure travel is figured between the most forward position and the position at the angle of Ky maximum/6.25. The values for the center of pressure travel are shown in Table I.

For comparison in diving, the moment coefficient with respect to the leading edge for the angle of zero lift is used.

$$\text{The moment coefficient} = \frac{M}{\rho A\, V^2 c} = \sqrt{Ky^2 + Kx^2} \times (Kc.p.)$$

Where M is the moment in inch-pounds about the leading edge.

A = area of aerofoil.
V = velocity of wind.
c = chord.
$Kc.p.$ = center of pressure coefficient.
Ky = lift coefficient.
Kx = drag coefficient.

The spar depths for the above-mentioned sections are also shown in Table I. All of the Dayton-Wright sections and the Gottingen No. 387 have sufficient spar depth for use as internally braced wings, except the Dayton-Wright No. 5.

DISCUSSION.

A comparison of the tests run at Gottingen and at Massachusetts Institute of Technology on the Gottingen No. 387 shows a considerable difference in results.

This difference is attributed to the fact that the section constructed in this country was built from the ordinates scaled by the N. A. C. A. off of a silhouette published in the Technische Berichte, and also due to the Gottingen test being run with a wind velocity of 67 miles per hour. The German model varied slightly from the Dayton-Wright at three points.

The Gottingen No. 387 has a very high left coefficient, but its aerodynamical efficiency is very much inferior to the U. S. A. 27. Its high-speed characteristic, however, is but slightly less than the U. S. A. 27, and its speed range is the same. The ceiling and climb for constant loading and constant landing speed are very poor as compared to the U. S. A. 27. Its maximum forward position of the center of pressure and the center of pressure travel are slightly inferior to the U. S. A. 27, but its spar depths are considerably superior to this section. It would seem that the Gottingen No. 387 would find its greatest use on a high-speed reconnaissance airplane, where speed and maneuverability are very desirable and where ceiling and high climbing rate are not so essential. It is handicapped, however, by a rather low cruising radius as determined by its maximum L/D, and by its instability at high angles of incidence.

The Dayton-Wright No. 5 compares very favorably throughout with the R. A. F. 15. Its maximum lift coefficient, efficiency, and cruising range are somewhat better, but its maximum speed and speed range are considerably less. It, however, has a superior ceiling and climb for constant loading and constant landing speed. The maximum forward position of the center of pressure is the same, while its center of pressure travel is 21 per cent as compared to 14 per cent for the R. A. F. 15. The D.W. No. 5 also has better spar depths than the English section. It has a very high speed for use on either high-speed reconnaissance or large bombers, but its spar depths are not great enough for extensive use on these types. Its greatest use should be in pursuit types.

The Dayton-Wright No. 6 falls into about the same class as the Gottingen No. 387. It has a slightly inferior maximum lift coefficient, a little better speed for all types of airplanes, a much superior speed range, but the poorest ceiling and climb for constant loading and constant landing speed of any section shown in Table I. Its maximum forward position of center of pressure and the center of pressure travel are reasonable, being 30.3 and 32.2 per cent, respectively. This section, like the Gottingen No. 387, is very unstable after the burble point is reached. It possesses very deep wing spars, better than the U. S. A. 27 and but slightly inferior to the Gottingen No. 387. The front and rear spars are almost of equal depth.

The two Dayton-Wright aerofoils Nos. TT–1 and TT–2 were not tested as sections with true flaps, but built up along the trailing edge as described above. It is not known just what effect this will have on the characteristics over that of the true flap section.

The Dayton-Wright No. TT–1 tested with adjustable surface at 0° possesses very good characteristics throughout. It has a high lift coefficient, good cruising and high-speed characteristics for all types of airplanes. Its speed range is very high, although the ceiling and climb for constant loading is very poor and for constant landing speed is just average. The maximum forward position of the center of pressure is rather far back, although the center of pressure travel is rather small, being 22.9 per cent. This section possesses spar depths much greater than the U. S. A. 27, making it a good section for the internally

braced wing type. This aerofoil would be a very good section for a high-speed, heavily loaded airplane, either a bomber or heavy duty commercial airplane.

The Dayton-Wright No. TT-2 possesses slightly better characteristics throughout, except for speed range and maximum forward position of the center of pressure, than the Dayton-Wright No. TT-1.

As the angle of the flap is increased on these two sections the lift increases very rapidly to the detriment of all other characteristics except the landing speed. The efficiency falls very rapidly. On both the D. W. TT-1 and TT-2 the center of pressure travel taken at the angle of Ky maximum/6.25 moves toward the trailing edge very rapidly as the flap angle is increased. However, to reach the angle of Ky maximum/6.25 with increase of flap angle creates a condition of flight where the angle of attack is far below the normal high-speed angle. Therefore, one of the advantages of the trailing edge flap is that it may be used to throw the center of pressure forward on the wing at high speeds by increasing the flap angle. It is observed that on the D. W. TT-1 the center of pressure location, with flap at 0° and at an angle of attack of −1° is 61 per cent back of the leading edge. If the angle of attack is held constant and the flap angle increased through the range of 45°, the center of pressure position may be moved forward until it is at 48.5 per cent of the wing chord. The center of pressure travel on the D. W. TT-2 at an angle of attack of −1° may, by operation of the flaps, be moved forward from a position at 60 per cent to a point about 48.5 per cent back on the wing chord. It is seen, therefore, that the adjustable flap may be used as a powerful control over the position of the center of pressure under high-speed conditions. This control of the center of pressure position is rather ineffective at climbing or landing speeds. At landing speeds the flaps play a very important rôle, in that they may be used to create a very high lift at very low speeds, or, in other words, they extend the speed range.

A comparison of these two sections with the Glenn Martin No. 2-F gives the following results: The maximum lift coefficient of the M-2-F with both leading and trailing edge flaps at 0° is given as 0.004 as compared to 0.00307 for the TT-1 and 0.00318 for the TT-2. There is considerable doubt as to the value of the very high lift coefficients obtained for very thick wing sections such as the M-2-F. Several tests were made on the M-2-F and it seems that in the neighborhood of 14° incidence the section may become unstable with the least unsteadiness of the wind or if there exists a slight flat spot on the model. One test gave a maximum Ky of 0.0033, and another gave 0.00358. The maximum lift coefficient of the M-2-F with the rear flap at 40° and the front flap at 0° is 0.00507, and with the rear flap at 50° is about 0.00480 as compared to 0.00482 for the TT-1 and 0.00499 for the TT-2, both sections with flaps at 45°.

The maximum L/D for the M-2-F with both flaps at 0° is 14.12 as compared to 14.8 for the TT-1 and 15.22 for the TT-2. The L/D at 8° incidence and with rear flap at 45° for the M-2-F is about 4.25 and for the TT-2 it is 3.2.

Figures 17 and 18 are the envelope curves of the Dayton-Wright Nos. TT-1 and TT-2 for L/D versus lift coefficient. The shaded area represents the increase for the various flap settings.

Table I.—*Comparative table of following aerofoil sections.*

Aerofoil.	R. A. F. 15.	U. S. A. 27.	Gottingen No. 387.	Dayton-Wright. No. 5.	Dayton-Wright. No. 6.	No. TT-1. 0°	No. TT-1. 15°	No. TT-1. 30°	No. TT-1. 45°	No. TT-2. 0°	No. TT-2. 15°	No. TT-2. 30°	No. TT-2. 45°
Maximum Ky (landing)	0.00258	0.00363	0.00415	0.00265	0.00398	0.00307	0.00394	0.00454	0.00485	0.00318	0.00406	0.00456	0.00499
Minimum Kx	.0000393	.000073	.000098	.00005	.000083	.000052	.00014	.000295	.00050	.00006	.000152	.000275	
Maximum L/D (cruising)	16.3	16.0	13.5	16.6	13.63	14.8	10.1	6.5	4.4	15.22	8.9	6.85	4.5
High speed, pursuit, L/D at 1/9 maximum Ky	7.7	4.6	4.5	6.5	5.4	5.65	3.1	1.65	1.00	6.2	2.95	1.4	1.3
High speed reconnaissance fighter, L/D at 1/6.25 maximum Ky	9.7	7.0	6.75	9.3	7.85	8.10	4.2	2.45	1.45	8.9	3.95	2.1	1.57
High speed, bomber, L/D at 1/4 maximum Ky	13.5	11.7	10.45	12.85	11.4	12.60	6.15	3.78	1.95	12.7	5.75	4.3	2.15
Speed range $\frac{\sqrt{Ky\ max.}}{\sqrt{Kx\ min.}}$	1.494	1.410	1.410	1.395	1.446	1.488	1.215	1.036	.88	1.445	1.24	1.04	
Ceiling and climb const. loading $\frac{Ky^{3/2}}{Kx}$ maximum	.615	.665	.623	.629	.604	.610	.542	.415	.305	.638	.528	.746	.307
Const. landing speed $\sqrt{\frac{Ky\ max.}{\frac{Ky}{L/D}}}$ minimum	.0827	.0908	.1035	.0818	.1045	.0912	.1168	.1620	.2360	.0877	.1245	.1561	.2310
Maximum forward position of C. P. (in case of tapered wings state what chord used)	29.0	27.4	32.0	29.0	30.3	35.1	40.4	43.0	42.7	35.8	40.8	42.5	44.0
C. P. travel in per cent chord between maximum forward position and position at angle of Ky maximum /6.25	14.0	39.6	41.0	21.0	32.2	22.9	46.6	48.0	[1] 62.3	19.8	43.2	41.0	25.5
Spar depths per cent of chord:													
10 per cent from leading edge	6.05	9.2	12.07	6.68	10.833	10.7484				13.530			
15 per cent from leading edge	6.31	10.4	13.83	7.11	12.377	12.542				15.330			
60 per cent from leading edge	5.30	9.2	11.05	5.80	10.583	10.778				11.820			
70 per cent from leading edge	4.80	7.9	8.62	5.09	8.783	8.9032				9.330			
Authority	M. I. T.	M. I. T.	M. I. T.	M. I. T.	M. I. T.	M. I. T.				M. I. T.			
Date test run	June, 1919	Nov., 1920	Aug., 1921	Aug., 1921	Aug., 1921	June, 1921				June, 1921			
Velocity of wind (m. p. h.)	30	30	30	30	30	30				30			
Aspect ratio	6	6	6	6	6	5.76				5.76			
McCook Field serial number		1460											

[1] Center of pressure at angle for Ky maximum /6.25 of chord.

TABLE II.—*Gottingen No. 387.*

Authority: Aerodynamical Laboratory, Massachusetts Institute of Technology, August, 1921.
Velocity: 30 miles per hour.
Model: 18 by 3 inches wood.

α	Ky.	Kx.	L/D.	M_{le}	C. P.
−10	−0.000295	0.000275	−1.07	−0.040	....
−8	−.000015	.000182	−.084	−.205	....
−6	+.000380	.000115	+3.31	−.385	....
−4	.000750	.000098	7.65	−.500	0.660
−2	.001150	.000102	11.30	−.572	.492
0	.001545	.000118	13.10	−.675	.429
+2	.001945	.000145	13.40	−.775	.393
4	.00233	.000182	12.75	−.877	.368
6	.00271	.000225	12.00	−.975	.350
8	.003075	.000275	11.15	−1.068	.339
10	.00341	.000330	10.30	−1.153	.331
12	.00371	.000390	9.52	−1.230	.328
14	.00398	.000450	8.85	−1.298	.324
16	.00415	.000515	8.06	−1.328	.320
18	.00237	.000858	2.76	−.988	.391
20	.00223	.000950	2.34	−.990	.402
22	.00221	.001045	2.11	−1.008	.410
24	.00224	.001145	1.955	−1.032	.410

M_{le}=moment about leading edge in inch pounds at 30 miles per hour

TABLE III.—*Dayton-Wright No. 5.*

Authority: Aerodynamical Laboratory, Massachusetts Institute of Technology, August, 1921.
Velocity: 30 miles per hour.
Model: 18 by 3 inches wood.

α	Ky.	Kx.	L/D.	M_{le}	C. P.
−4	−0.00024	0.000062	−3.86	−0.019	....
−2	+.00014	.000053	+2.67	−.112	0.777
0	+.00072	.000052	+13.73	−.297	.407
+2	+.00115	.000069	16.54	−.401	.347
4	.00153	.000095	16.02	−.493	.317
6	.00189	.000131	14.41	−.585	.303
8	.00227	.000172	13.20	−.690	.297
10	.00261	.000221	11.84	−.768	.290
12	.00263	.000376	6.99	−.828	.307
14	.00243	.000562	4.33	−.878	.347
16	.00229	.000696	3.29	−.917	.377
18	.00224	.000792	2.83	−.934	.387
22	.00220	.000983	2.23	−.947	.387
26	.00225	.001182	1.91	−1.013	.390
30	.00236	.001469	1.61	−1.129	.400

M_{le}=moment about leading edge in inch pounds at 30 miles per hour.

TABLE IV.—*Dayton-Wright No. 6.*

Authority: Aerodynamical Laboratory, Massachusetts Institute of Technology, August, 1921.
Velocity: 30 miles per hour.
Model: 18 by 3 inches wood.

α	Ky.	Kx.	L/D.	M_{le}	C. P.
−8	−0.00035	0.000178	−1.97	....	....
−6	+.00014	.000104	+1.37	−0.287	....
−4	+.00056	.000082	6.76	−.392	0.700
−2	.00090	.000085	10.63	−.464	.507
0	.00134	.000098	13.58	−.584	.430
+2	.00168	.000124	13.54	−.664	.387
4	.00207	.000160	12.93	−.756	.360
6	.00245	.000201	12.20	−.859	.343
8	.00279	.000247	11.31	−.940	.330
10	.00313	.000302	10.36	−1.032	.323
12	.00342	.000353	9.69	−1.105	.317
14	.00369	.000412	8.96	−1.161	.310
16	.00394	.000464	8.49	−1.219	.307
18	.00397	.000544	7.31	−1.223	.303
22	.00230	.000996	2.31	−.974	.380
26	.00218	.001180	1.83	−.975	.387
30	.00224	.001433	1.56	−1.071	.397

M_{le}=moment about leading edge in inch pounds at 30 miles per hour.

TABLE V.—*Dayton-Wright No. TT-1.*

Authority: Aerodynamical Laboratory, Massachusetts Institute of Technology, June, 1921.
Velocity: 30 miles per hour.
Model: 17.453 by 3.777 inches bakelite.

α	Ky.				Kx.				L/D.				Moment coefficient.				Center of pressure.			
	0°	15°	30°	45°	0°	15°	30°	45°	0°	15°	30°	45°	0°	15°	30°	45°	0°	15°	30°	45°
−16				−0.001				0.000565				−1.80								
14				−.00057				.000502				−1.10								
12			−0.00094	+.00045			0.000385	.000542			−2.48	+.90				−0.00636				
10			−.00013	.00164		0.000305	.000330	.000632		−5.0	−.35	2.57			−0.00636	−.01200				68.0
8		−0.00038	+.00083	.00208	0.000235	.000185	.000300	.000680	−4.72	−1.9	+2.74	3.08		−0.00216	−.00864	−.01440			87.0	57.6
6	−0.00072	+.00038	.00139	.00243	.000140	.000140	.000310	.000710	−4.48	+2.8	4.45	3.42		−.00504	−.01056	−.01548			66.0	53.0
4	−.00031	.00090	.00180	.00275	.000080	.000150	.000345	.000740	−3.84	5.7	5.36	3.70		−.00720	−.01224	−.01644		72.0	57.8	49.8
2	+.00015	.00130	.00217	.00310	.000055	.000165	.000380	.000784	+2.65	8.0	5.78	3.98	−0.00180	−.00888	−.01398	−.01788	100.0	56.5	53.0	47.8
0	.00071	.00172	.00261	.00340	.000060	.000185	.000425	.000835	11.50	9.5	6.15	4.16	−.00432	−.01056	−.01548	−.01937	50.5	49.8	49.8	46.1
+2	.00113	.00216	.00303	.00385	.000075	.000215	.000470	.000900	14.72	10.08	6.40	4.30	−.00588	−.01212	−.01710	−.02076	43.5	47.0	47.8	45.0
4	.00151	.00257	.00342	.00422	.000105	.000255	.000530	.000960	14.62	10.02	6.50	4.38	−.00720	−.01380	−.01888	−.02208	40.0	44.8	46.0	44.0
6	.00188	.00300	.00382	.00452	.000135	.000310	.000590	.001035	13.85	9.72	6.50	4.38	−.00840	−.01548	−.02070	−.02340	38.0	43.0	44.8	43.0
8	.00228	.00337	.00421	.00482	.000180	.000365	.000655	.001120	12.75	9.25	6.40	4.24	−.00960	−.01704	−.02220	−.02448	36.8	41.6	44.0	42.5
10	.00263	.00375	.00449	.00482	.000230	.000432	.000735	.001270	11.55	8.64	6.12	3.75	−.01129	−.01836	−.02310	−.02502	36.0	40.6	43.0	43.1
12	.00295	.00392	.00453	.00443	.000285	.000510	.000900	.001550	10.35	7.18	5.10	2.85	−.01260	−.01900	−.02340	−.02400	35.5	40.7	43.0	45.0
14	.00307	.00388	.00432	.00367	.000360	.000710	.001150	.001720	8.50	5.30	3.60	2.12	−.01308	−.01920	−.02334	−.02040	35.8	41.6	45.3	46.5
16	.00287	.00355	.00382	.00346	.000560	.000955	.001340	.001860	4.90	3.70	2.80	1.85	−.01368	−.01885	−.02148	−.01968	39.6	44.0	47.0	47.5
18	.00269	.00327	.00345	.00323	.000750	.001120	.001455	.002020	3.57	3.00	2.34	1.65	−.01356	−.01812	−.01956	−.01878	42.3	46.0	47.0	48.0
20	.00252	.00303	.00318	.00303	.000875	.001240	.001555	.002220	2.88	2.42	2.02	1.42	−.01320	−.01716	−.01800	−.01752	43.8	47.0	47.0	48.6
22	.00236	.00282	.00299	.00283	.000965	.001335	.001640		2.40	2.00			−.01249	−.01620	−.01686		44.2	47.8	46.8	
24	.00220		.00287	.00266	.001500	.001390	.001735		2.10	1.62			−.01163	−.01536	−.01608		44.0	48.0	46.5	

TABLE VI.—*Dayton-Wright No. TT-2.*

Authority: Aerodynamical Laboratory, Massachusetts Institute of Technology, June, 1921.
Velocity: 30 miles per hour.
Model: 17.453 by 3.777 inches bakelite.

α	Ky.				Kx.				L/D.				Moment coefficient.				Center of pressure.			
	0°	15°	30°	45°	0°	15°	30°	45°	0°	15°	30°	45°	0°	15°	30°	45°	0°	15°	30°	45°
−16				−0.00012				0.000500				−0.3								
−14				+.00075				.000555				+1.50								76.5
−12			−0.00058	.00180			0.000345	.000620			−1.65	2.86								65.0
−10		−0.00086	+.00012	.00226		0.000285	.000285	.000660		−3.0	−1.25	3.40								59.0
−8		−.00019	.00101	.00263		.000195	.000275	.000700		−1.25	+3.75	3.74			−0.00901	−0.01700			75.0	54.8
−6		+.00047	.00141	.00299		.000155	.000298	.000760		+3.10	5.18	4.00		−0.00564	−.01072	−.01870		99.0	62.5	51.8
−4	−0.00019	.00094	.00193	.00316	0.000070	.000161	.000332	.000815	−2.65	5.45	5.80	4.14		−.00760	−.01318	−.02500		68.0	55.8	49.8
−2	+.00025	.00138	.00234	.00373	.000060	.000182	.000372	.000865	+4.50	7.55	6.24	4.35	−0.002638	−.00953	−.01477	−.02218	85.5	55.8	51.2	48.0
0	.00069	.00182	.00276	.00409	.000062	.000210	.000425	.000900	11.25	8.74	6.55	4.46	−.004240	−.01144	−.01665	−.02359	49.5	50.7	48.5	46.5
+2	.00113	.00222	.00315	.00445	.000075	.000248	.000472	.000985	14.75	9.00	6.72	4.50	−.006200	−.01310	−.01830	−.02510	44.0	47.4	46.5	45.0
4	.00152	.00264	.00357	.00479	.000100	.000290	.000520	.001075	15.00	9.10	6.82	4.44	−.007820	−.01485	−.02008	−.02665	41.0	45.2	45.0	44.3
6	.00193	.00304	.00398	.00499	.000135	.000335	.000580	.001205	14.15	9.00	6.82	4.10	−.009380	−.01658	−.02200	−.02780	39.0	43.7	44.0	44.0
8	.00232	.00344	.00418	.00459	.000175	.000395	.000655	.001435	13.25	8.65	6.68	3.18	−.010860	−.01810	−.02336	−.02755	37.8	42.2	43.2	46.7
10	.00270	.00382	.00456	.00390	.000222	.000462	.000755	.001620	12.15	8.30	6.05	2.45	−.01220	−.01953	−.02440	−.02550	36.15	41.0	42.5	49.5
12	.00299	.00406	.00412	.00362	.000280	.000492	.001025	.001775	10.65	7.50	4.00	2.05	−.01332	−.02065	−.02400	−.02440	35.9	41.0	45.6	50.5
14	.00318	.00374	.00366	.00352	.000348	.000830	.001210	.001915	9.10	4.50	3.00	1.80	−.01420	−.02080	−.02260	−.02440	36.0	43.8	48.0	50.8
16	.00305	.00332	.00332	.00341	.000600	.000990	.001350	.002040	4.75	3.35	2.45	1.65	−.01530	−.02000	−.02140	−.02436	39.8	46.6	48.5	51.0
18	.00253	.00302	.00307	.00320	.000765	.001125	.001455	.002155	3.05	2.70	2.10	1.50	−.01440	−.01910	−.02056		43.8	47.9	49.0	
20	.00225	.00280	.00299	.00290	.000872	.001240	.001550	.002250	2.45	2.28		1.35	−.01336	−.01850			44.7	48.5	49.0	
22	.00216	.00269			.000936	.001325			2.20	2.00							45.0	48.8		
24	.00213	.00262			.000975	.001400			2.10								45.0	48.8		

TABLE VII.—*Ordinates of the Gottingen No. 387, Dayton-Wright Nos. 5, 6, TT-1 and TT-2, expressed in per cent of chord.*

Per cent of chord.	Gottingen No. 387.		Dayton-Wright.							
			No. 5.		No. 6.		No. TT-1.		No. TT-2.	
	Lower.	Upper.	Lower.	Upper.	Lower.	Upper.	Lower.	Upper.	Lower.	Upper.
0.00	3.61	3.61	1.83	1.83	3.083	3.083	0.0000	0.0000	0.00	0.00
1.25	1.35	6.74	.90	3.47	1.266	5.216	−1.5097	2.1303	....	3.00
2.50	.80	7.98	.47	4.30	.833	6.467	−1.7806	3.4000	−3.50	4.30
5.00	.35	9.86	.08	5.43	.333	8.383	−2.2000	5.3032	−4.23	6.13
7.50	.18	11.20	.00	6.20	.133	9.783	−2.5290	6.8645	−4.71	7.45
10.00	.13	12.20	.05	6.73	.050	10.883	−2.8000	7.9484	−5.00	8.53
11.56					.000	11.466				
15.00	.00	13.83	.25	7.36	.073	12.450	−3.1612	9.3807	−5.18	10.15
20.00	.07	14.77	.50	7.63	.167	13.400	−3.3290	10.2774	−5.00	11.28
30.00	.21	15.36	.90	7.73	.367	13.967	−3.1613	11.0194	−4.40	12.28
40.00	.37	14.88	.90	7.43	.450	13.500	−2.7290	10.7225	−3.80	12.05
50.00	.54	13.49	.68	6.90	.300	12.300	−2.2613	10.0194	−3.20	10.96
60.00	.54	11.59	.33	6.13	.150	10.733	−1.9006	8.8774	−2.56	9.26
70.00	.54	9.16	.07	5.16	.033	8.816	−1.5290	7.3742	−2.03	7.30
75.00					.000	7.667				
80.00	.49	6.57	.00	4.06	.033	6.367	−1.1606	5.4774	−1.38	5.06
90.00	.27	3.61	.20	2.75	.117	3.767	− .7000	3.1161	− .78	2.68
95.00			.35	1.85	.200	2.300	− .4600	1.7774		
100.00	.00	.36	.75	.75	.567	.000	.0000	.0000	.00	.00

Gottingen No. 387, radius L. E.=3.25, T. E.=0.20.
Dayton-Wright No. 5, radius L. E.=0.40, T. E.=0.15.
Dayton-Wright No. 6, radius L. E.=1.73, T. E.=0.20.
Dayton-Wright No. TT-1, radius L. E.=1.6161, T. E.=0.2761.
Dayton-Wright No. TT-2, radius L. E.=3.70, T. E.=0.133.

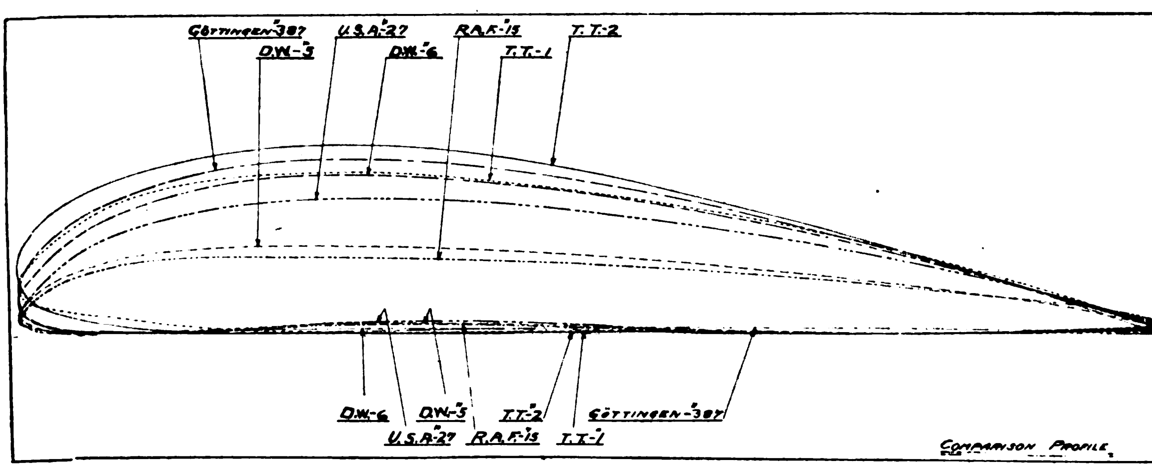


FIG. 1.

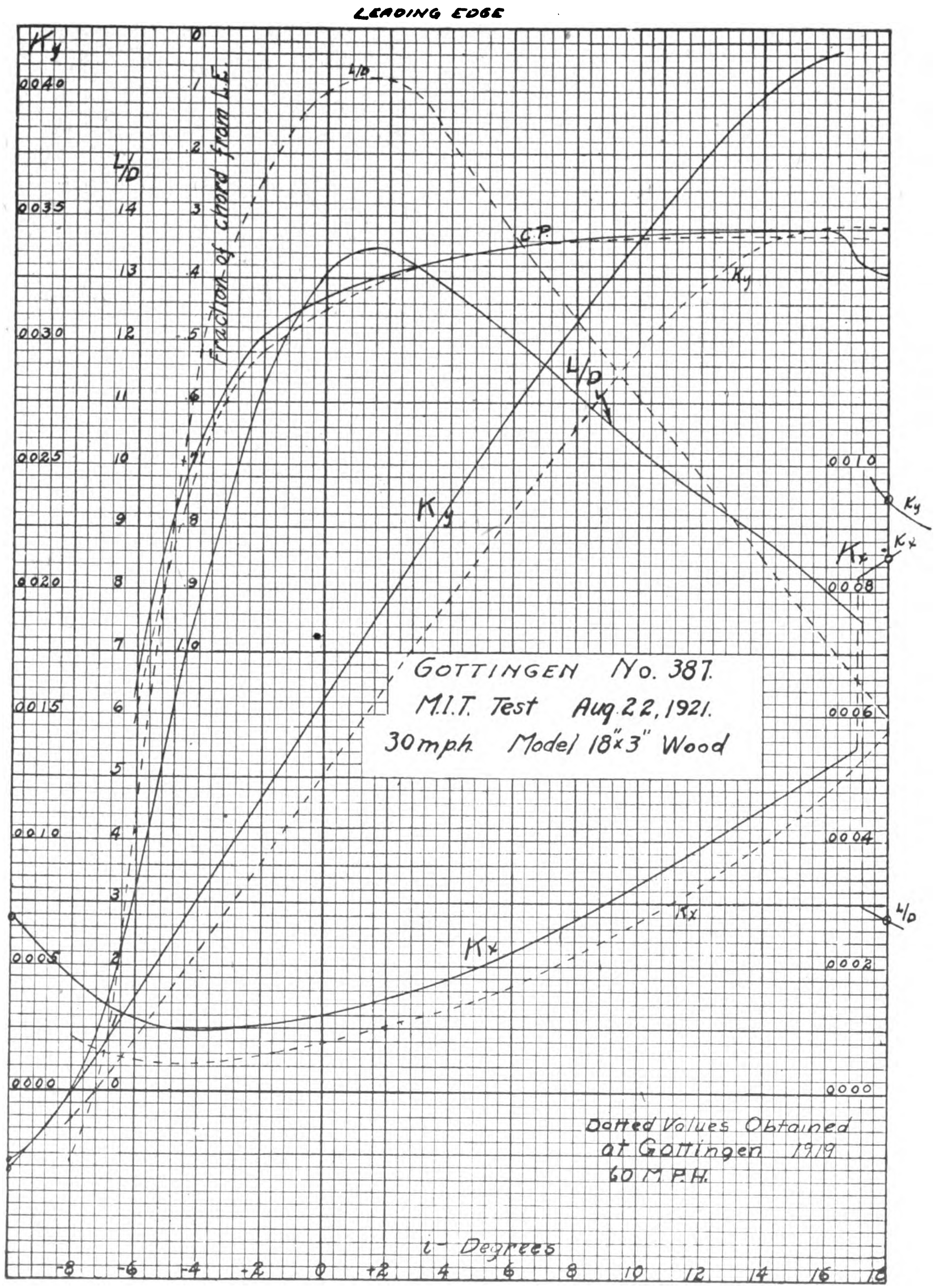

LEADING EDGE
Ky
L/D
Fraction of chord from L.E.
GOTTINGEN No. 387.
M.I.T. Test Aug. 22, 1921.
30 mph. Model 18" x 3" Wood
C.P.
L/D
Ky
Kx
Dotted Values Obtained at Gottingen 1919 60 M.P.H.
i - Degrees

FIG. 2.

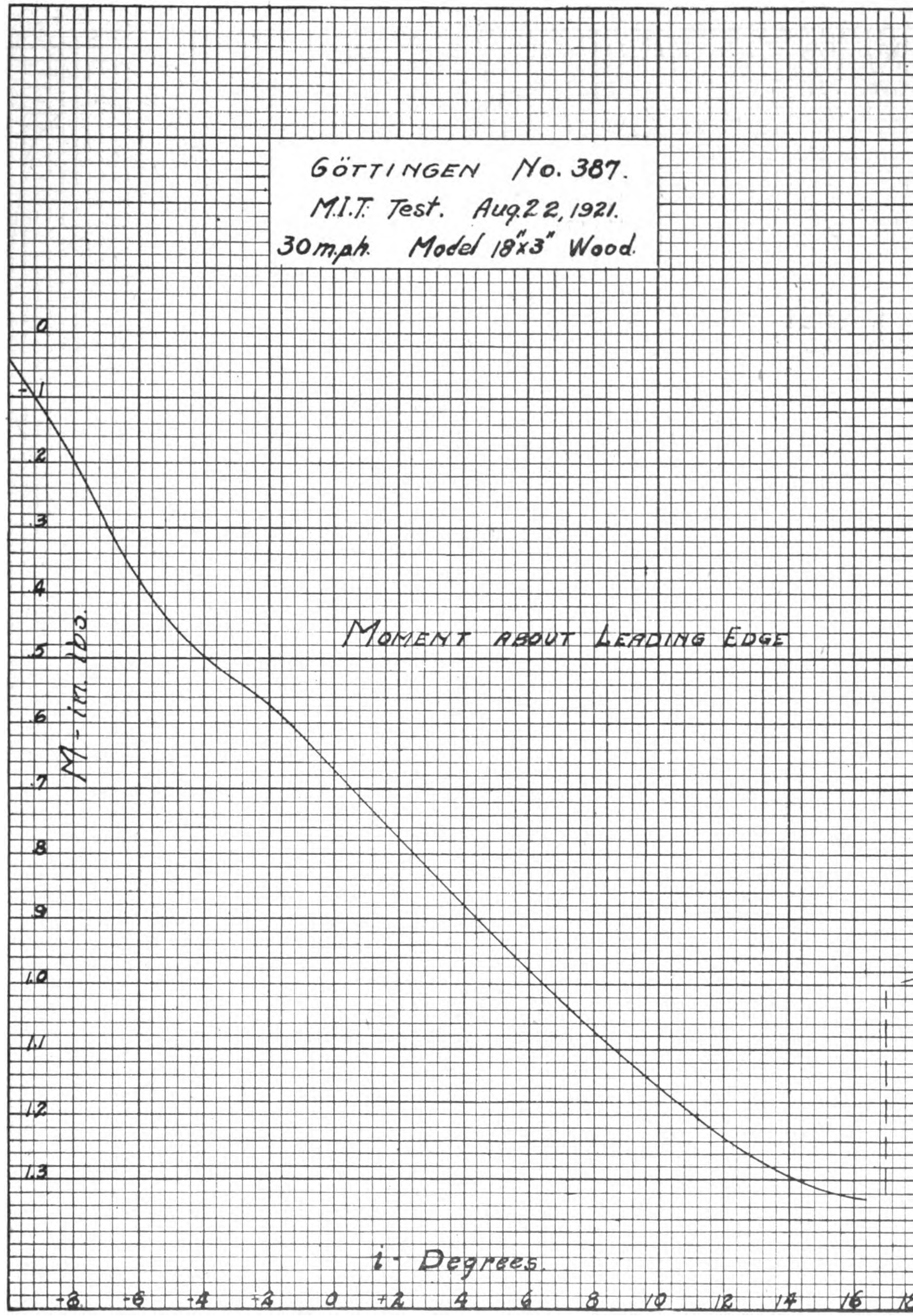

GÖTTINGEN No. 387.
M.I.T. Test. Aug. 22, 1921.
30 m.p.h. Model 18"x3" Wood.
Moment about Leading Edge
M - in. lbs.
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
i - Degrees.
-8
-6
-4
-2
0
+2
4
6
8
10
12
14
16
18

FIG. 3.

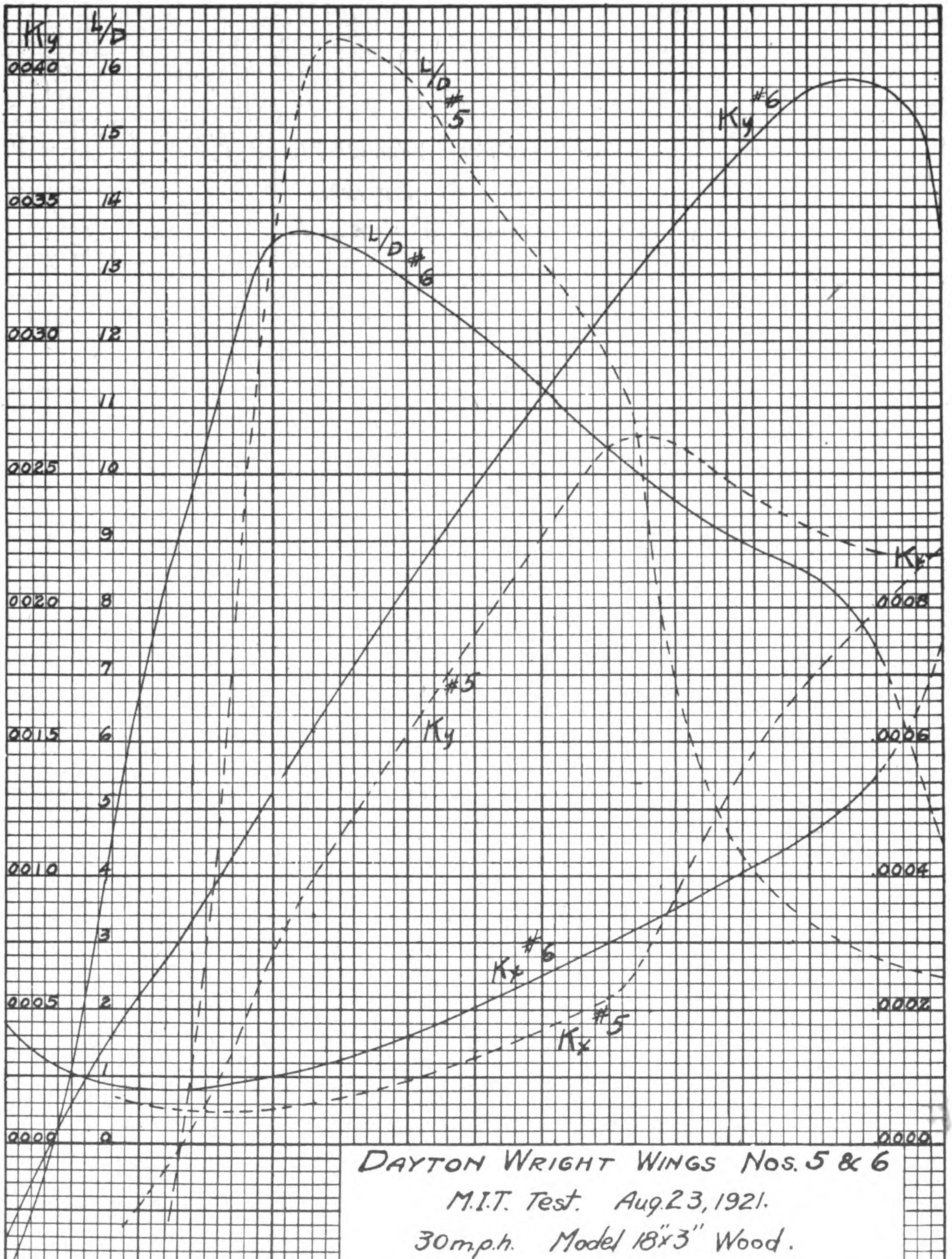

Ky
L/D
.0040
.0035
.0030
.0025
.0020
.0015
.0010
.0005
.0000
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
.0008
.0006
.0004
.0002
.0000
L/D #5
L/D #6
Ky #6
Ky #5
Kx
Kx #6
Kx #5
DAYTON WRIGHT WINGS NOS. 5 & 6
M.I.T. Test. Aug. 23, 1921.
30 m.p.h. Model 18" x 3" Wood.
i - Degrees.
-6
-4
-2
0
+2
4
6
8
10
12
14
16
18
20

FIG. 4.

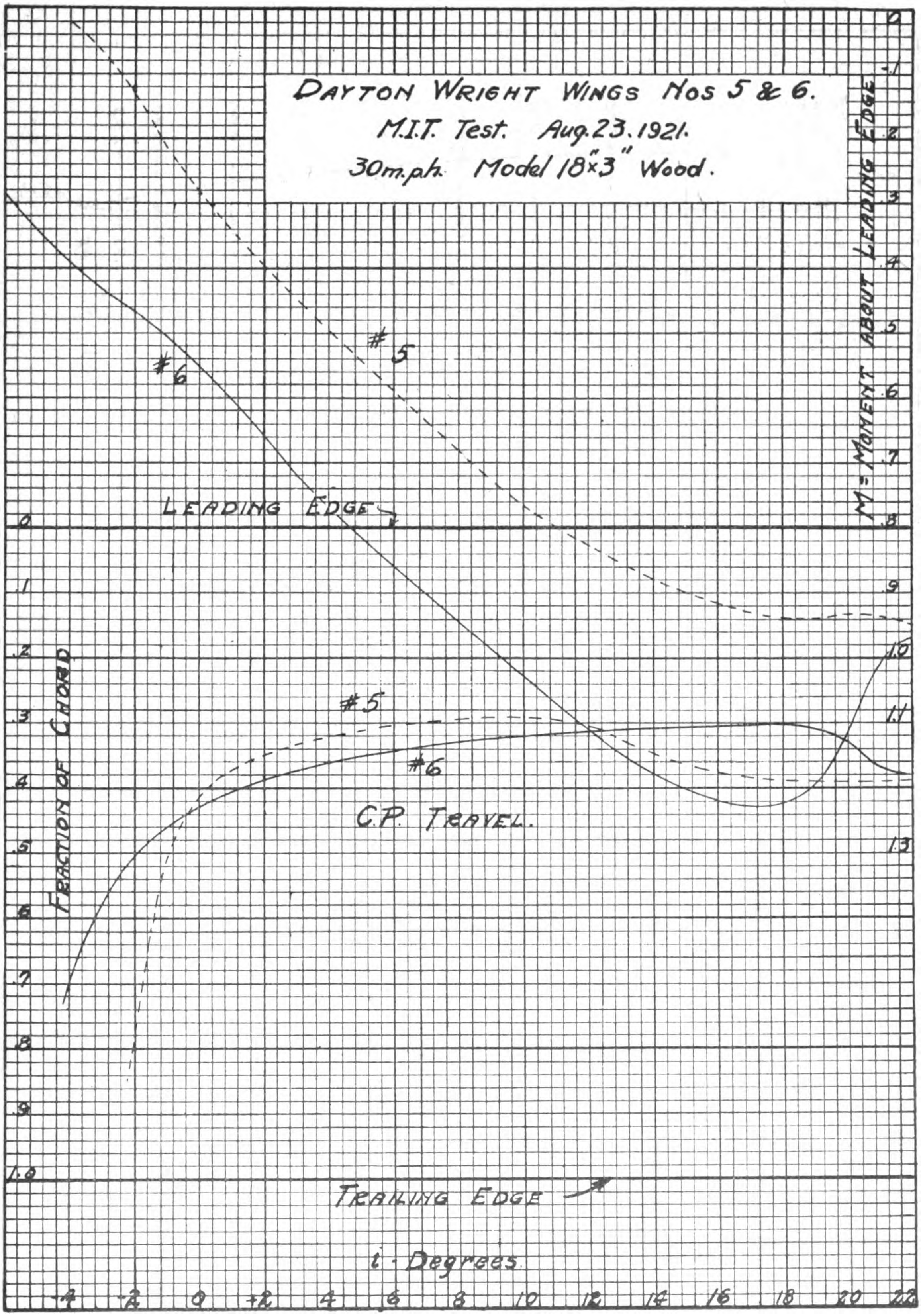

DAYTON WRIGHT WINGS NOS 5 & 6.
M.I.T. Test. Aug. 23. 1921.
30 m.p.h. Model 18"×3" Wood.
#5
#6
LEADING EDGE
#5
#6
C.P. TRAVEL.
FRACTION OF CHORD
M = MOMENT ABOUT LEADING EDGE
TRAILING EDGE
i - Degrees
-4
-2
0
+2
4
6
8
10
12
14
16
18
20
22
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.3

FIG. 5.

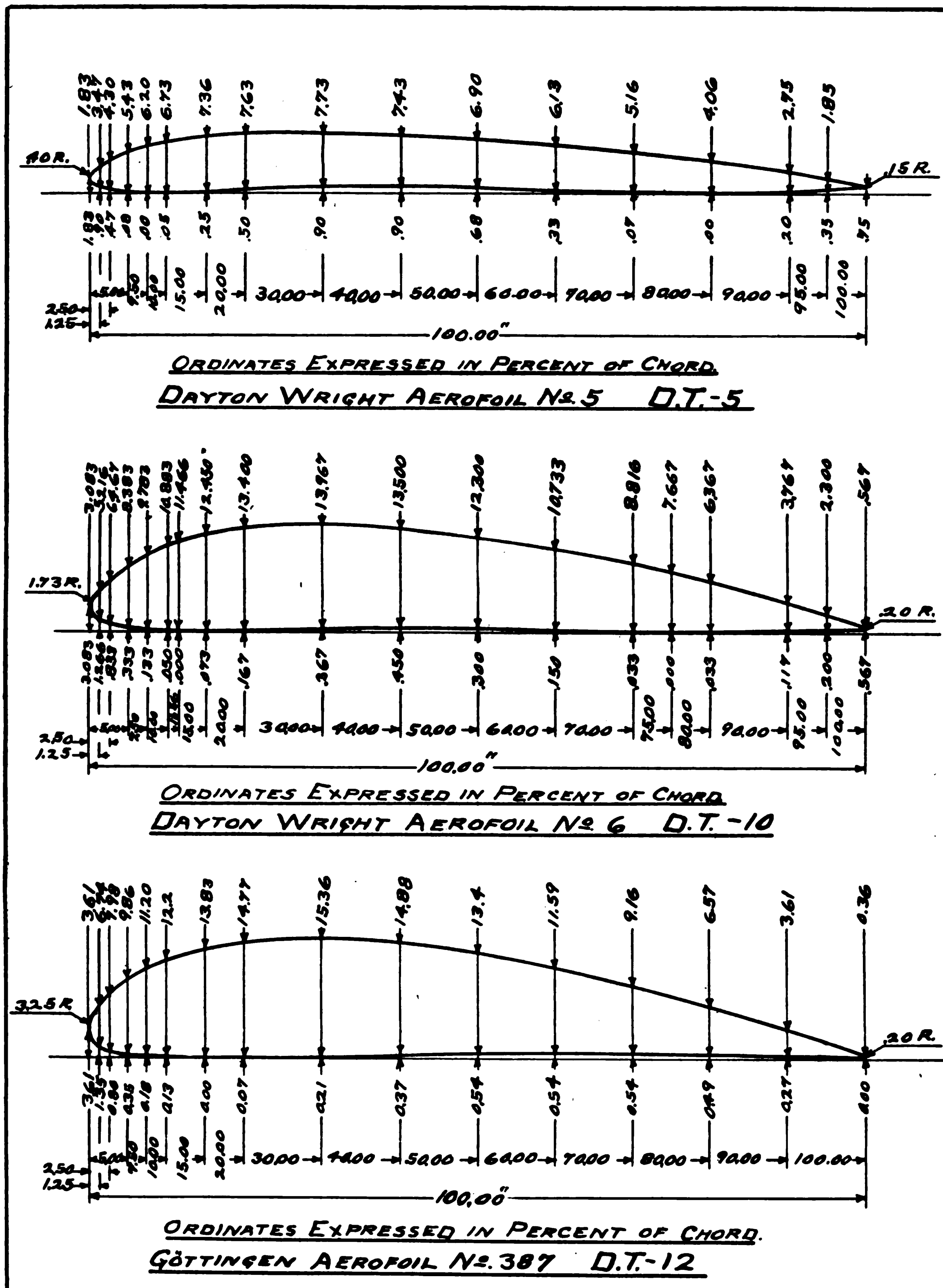

Ordinates Expressed in Percent of Chord.
Dayton Wright Aerofoil No. 5 D.T.-5
Ordinates Expressed in Percent of Chord.
Dayton Wright Aerofoil No. 6 D.T.-10
Ordinates Expressed in Percent of Chord.
Göttingen Aerofoil No. 387 D.T.-12

Fig. 6.

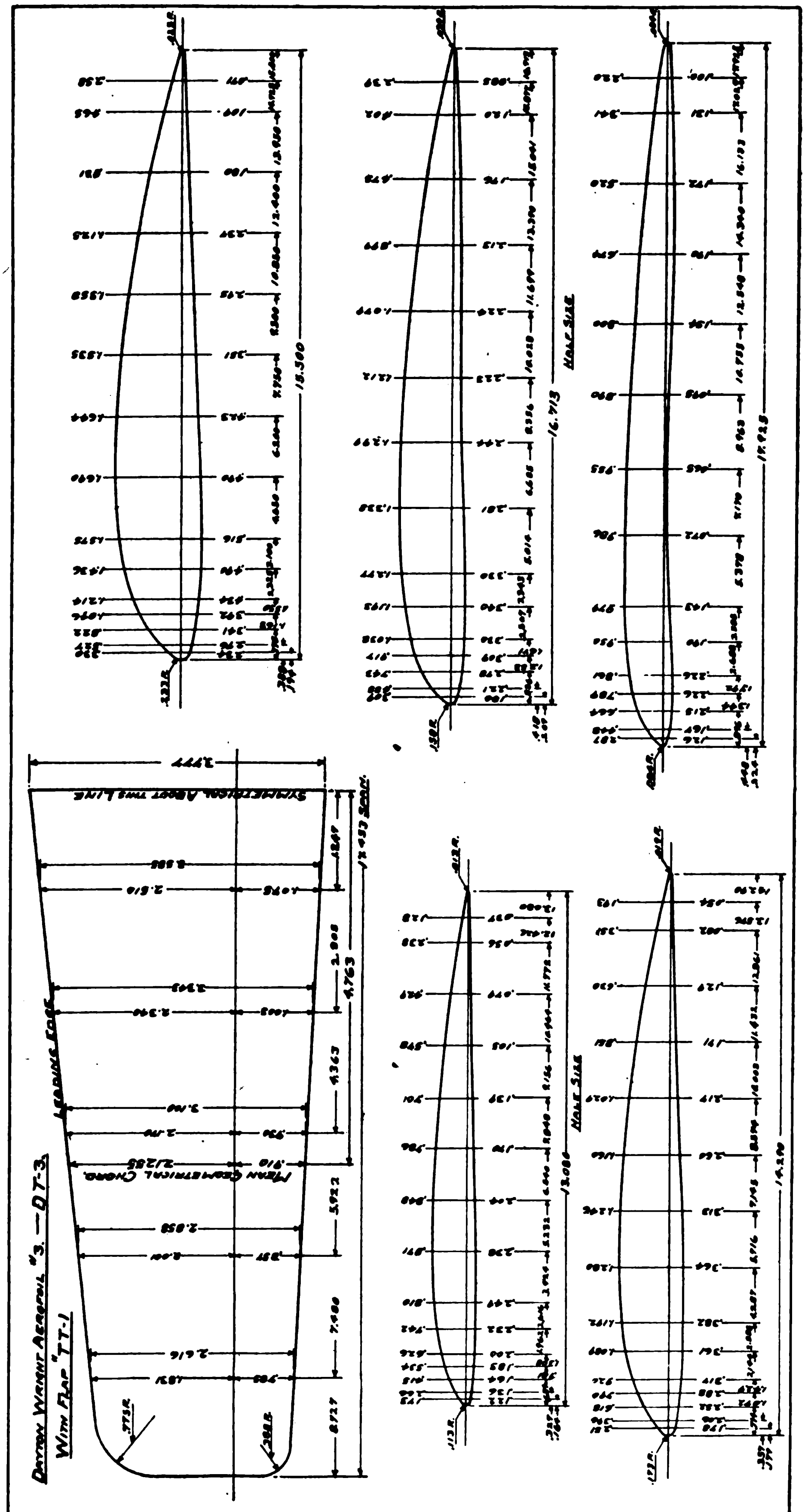

DAYTON WRIGHT AEROFOIL #3. —DT-3.
WITH FLAP "TT-1"
LEADING EDGE
SYMMETRICAL ABOUT THIS LINE
MEAN GEOMETRICAL CHORD
SPAN
HALF SIZE
HALF SIZE

FIG. 7.

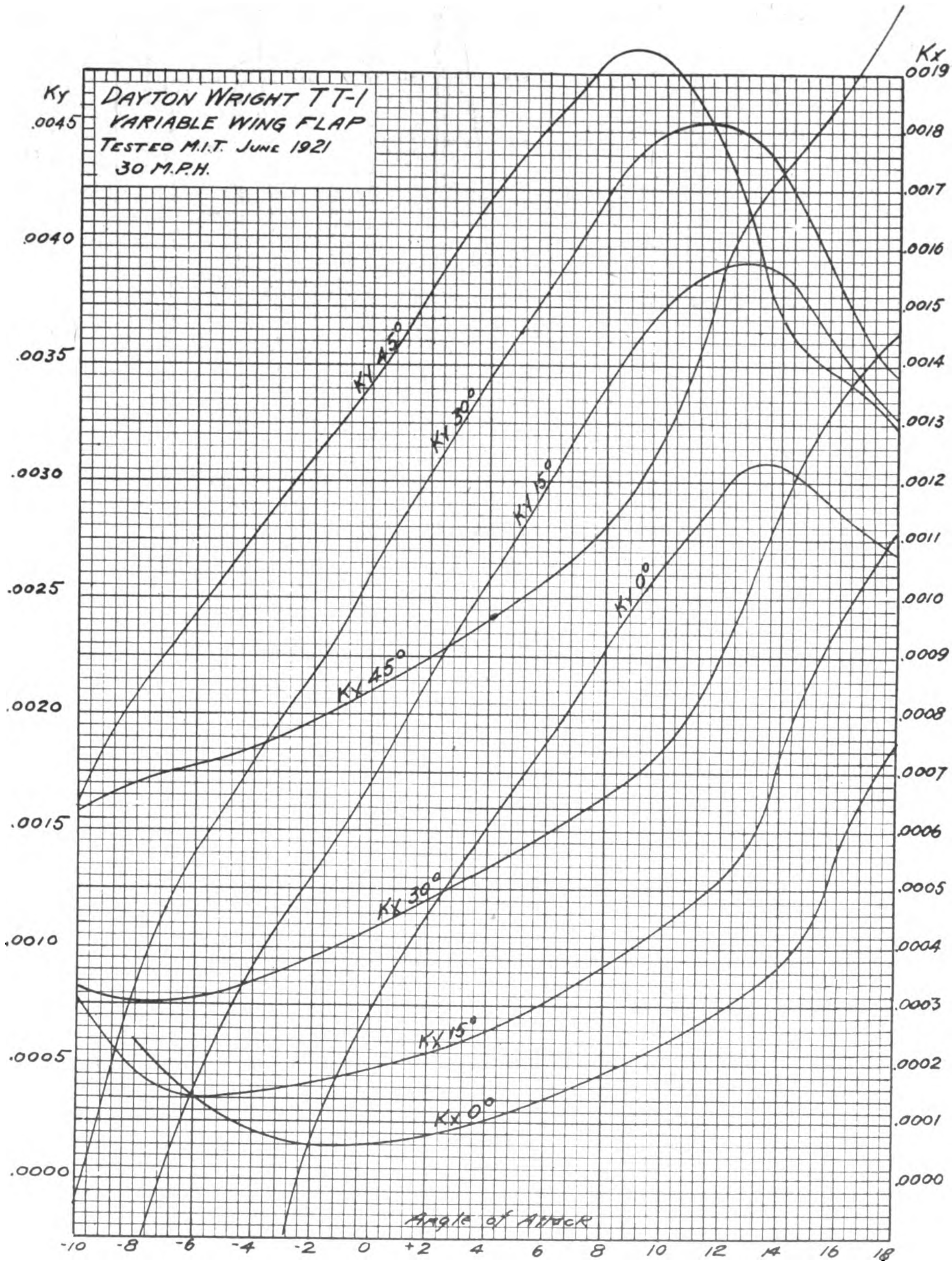
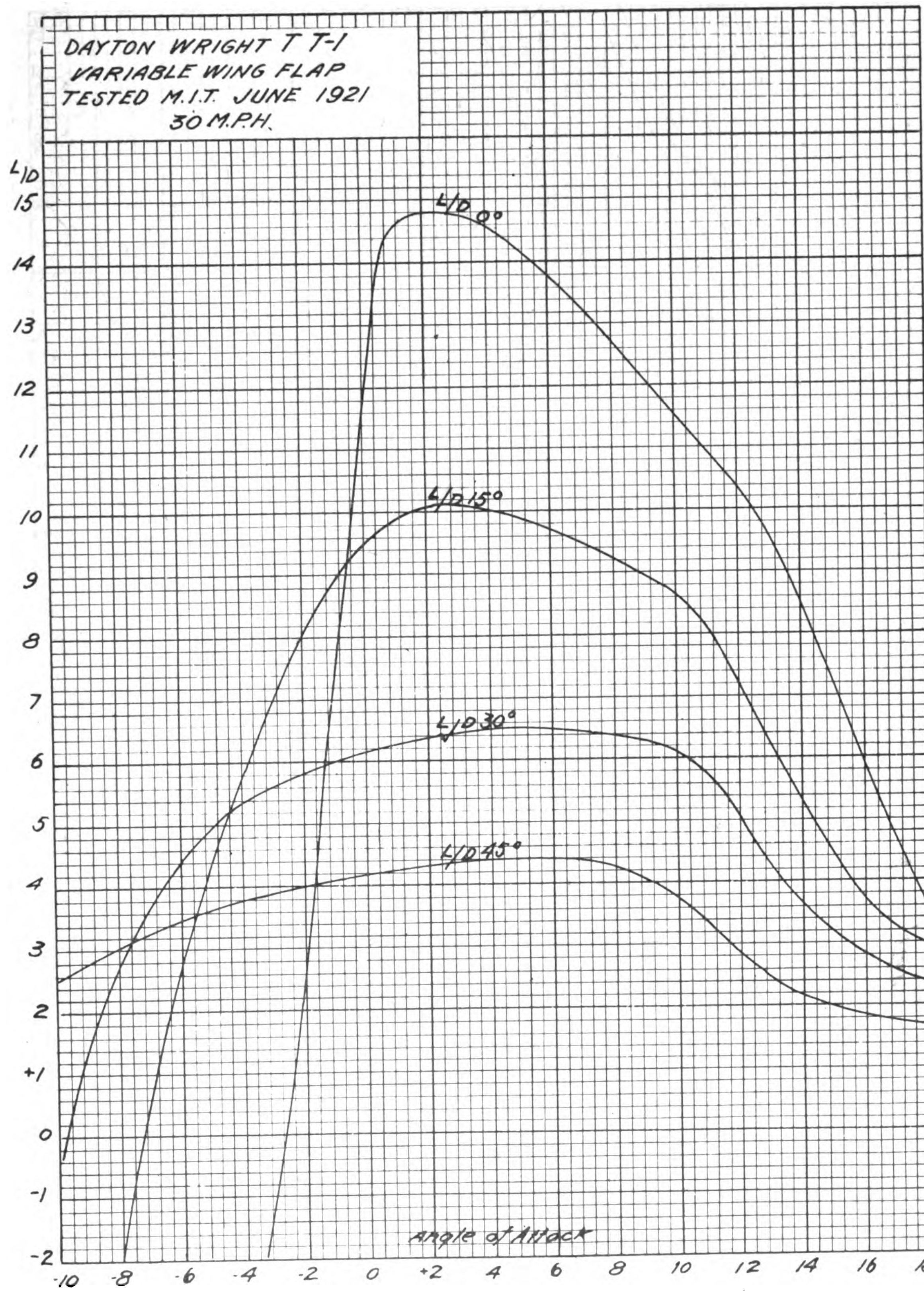

DAYTON WRIGHT TT-1
VARIABLE WING FLAP
TESTED M.I.T. JUNE 1921
30 M.P.H.
Ky
Kx
Ky 45°
Ky 30°
Ky 15°
Ky 0°
Kx 45°
Kx 30°
Kx 15°
Kx 0°
Angle of Attack
.0045
.0040
.0035
.0030
.0025
.0020
.0015
.0010
.0005
.0000
.0019
.0018
.0017
.0016
.0015
.0014
.0013
.0012
.0011
.0010
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
.0000
-10
-8
-6
-4
-2
0
+2
4
6
8
10
12
14
16
18

FIG. 8.



DAYTON WRIGHT T T-1
VARIABLE WING FLAP
TESTED M.I.T. JUNE 1921
30 M.P.H.
L/D
15
14
13
12
11
10
9
8
7
6
5
4
3
2
+1
0
-1
-2
L/D 0°
L/D 15°
L/D 30°
L/D 45°
Angle of Attack
-10
-8
-6
-4
-2
0
+2
4
6
8
10
12
14
16
18

FIG. 9.

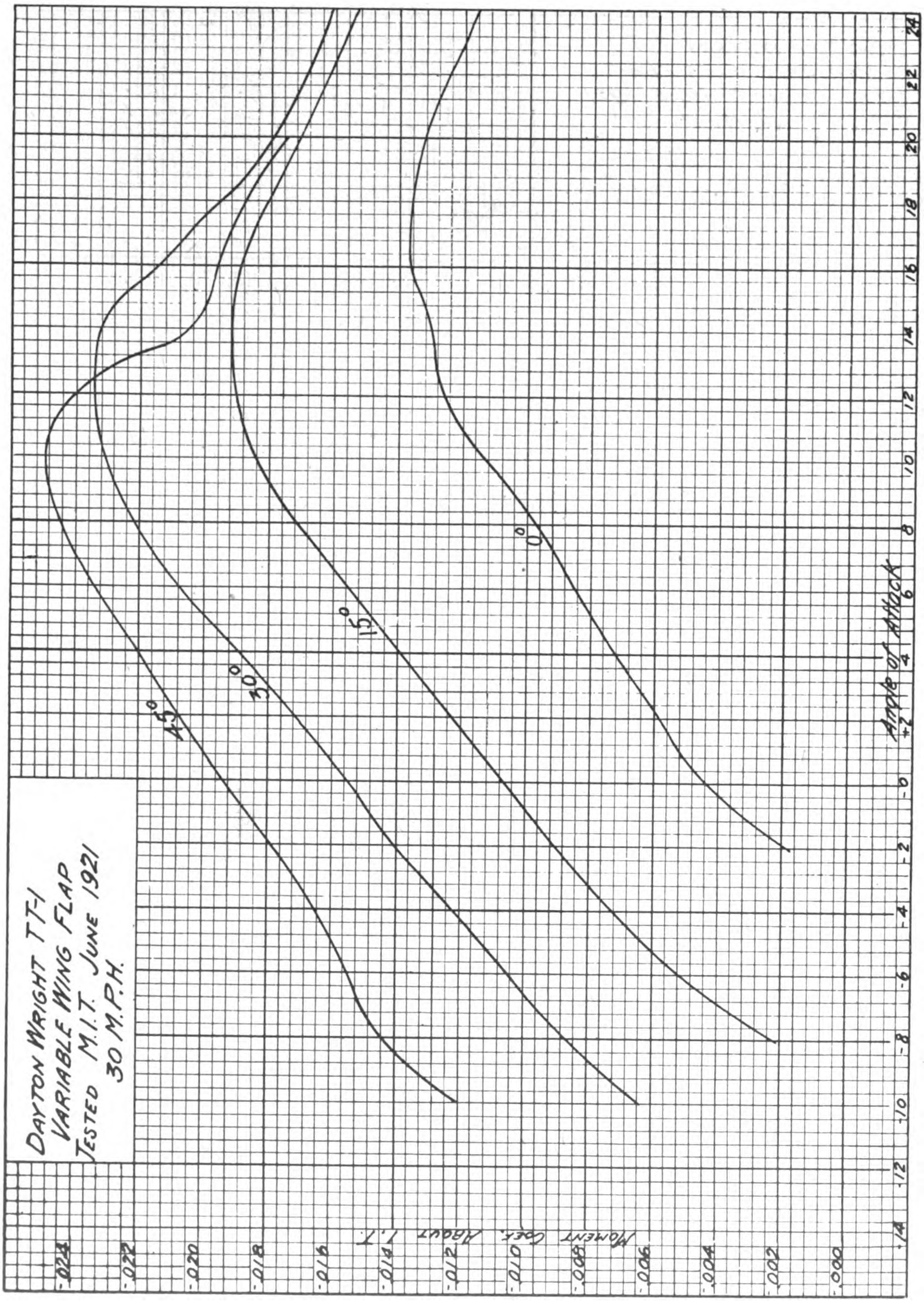
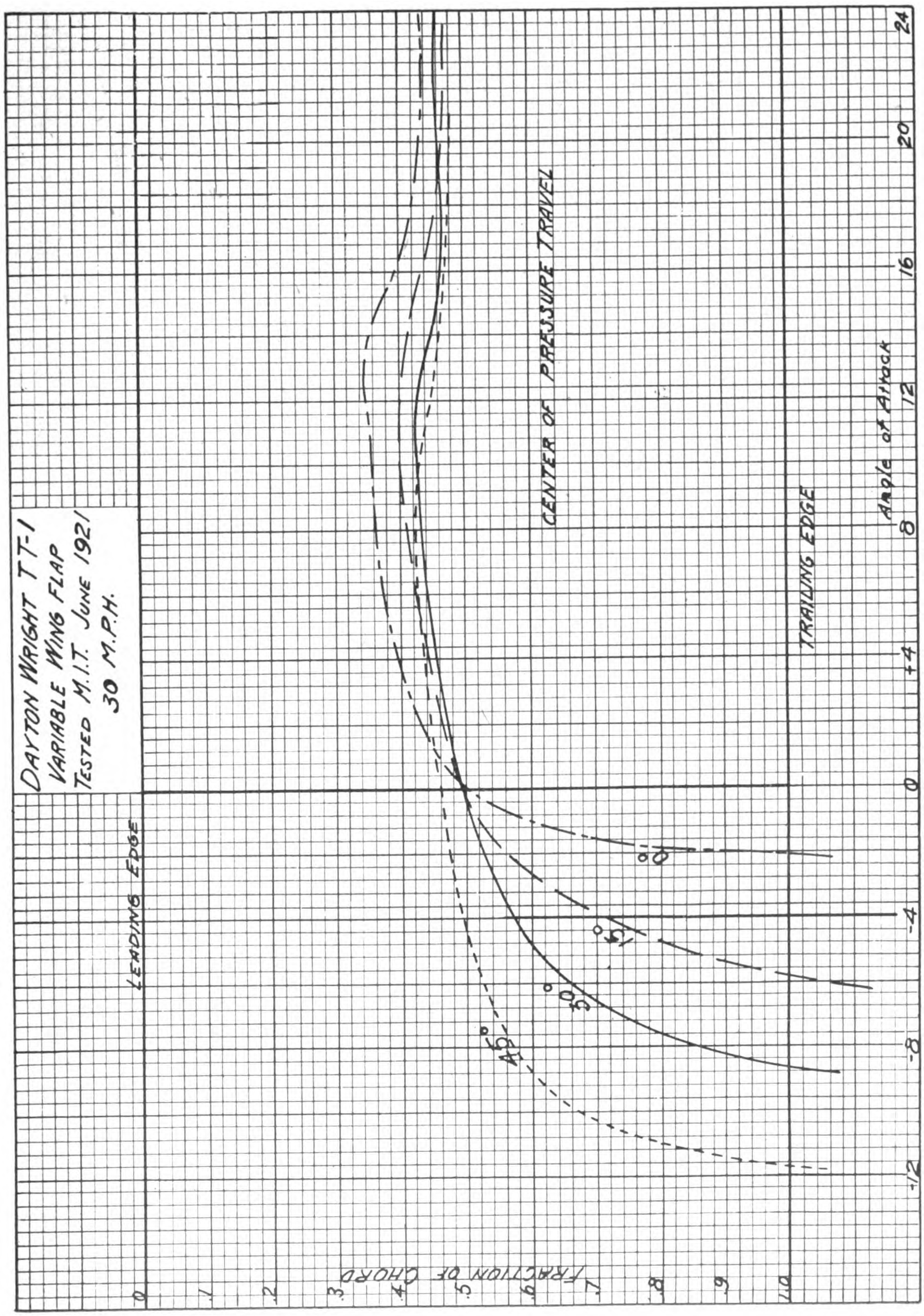

DAYTON WRIGHT TT-1
VARIABLE WING FLAP
TESTED M.I.T. JUNE 1921
30 M.P.H.
45°
30°
15°
0°
Angle of Attack
Moment Coef.

FIG. 10.



DAYTON WRIGHT TT-1
VARIABLE WING FLAP
TESTED M.I.T. JUNE 1921
30 M.P.H.
LEADING EDGE
CENTER OF PRESSURE TRAVEL
TRAILING EDGE
Angle of Attack
FRACTION OF CHORD
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
-12
-8
-4
0
+4
8
12
16
20
24
45°
30°
15°
0°

FIG. 11.

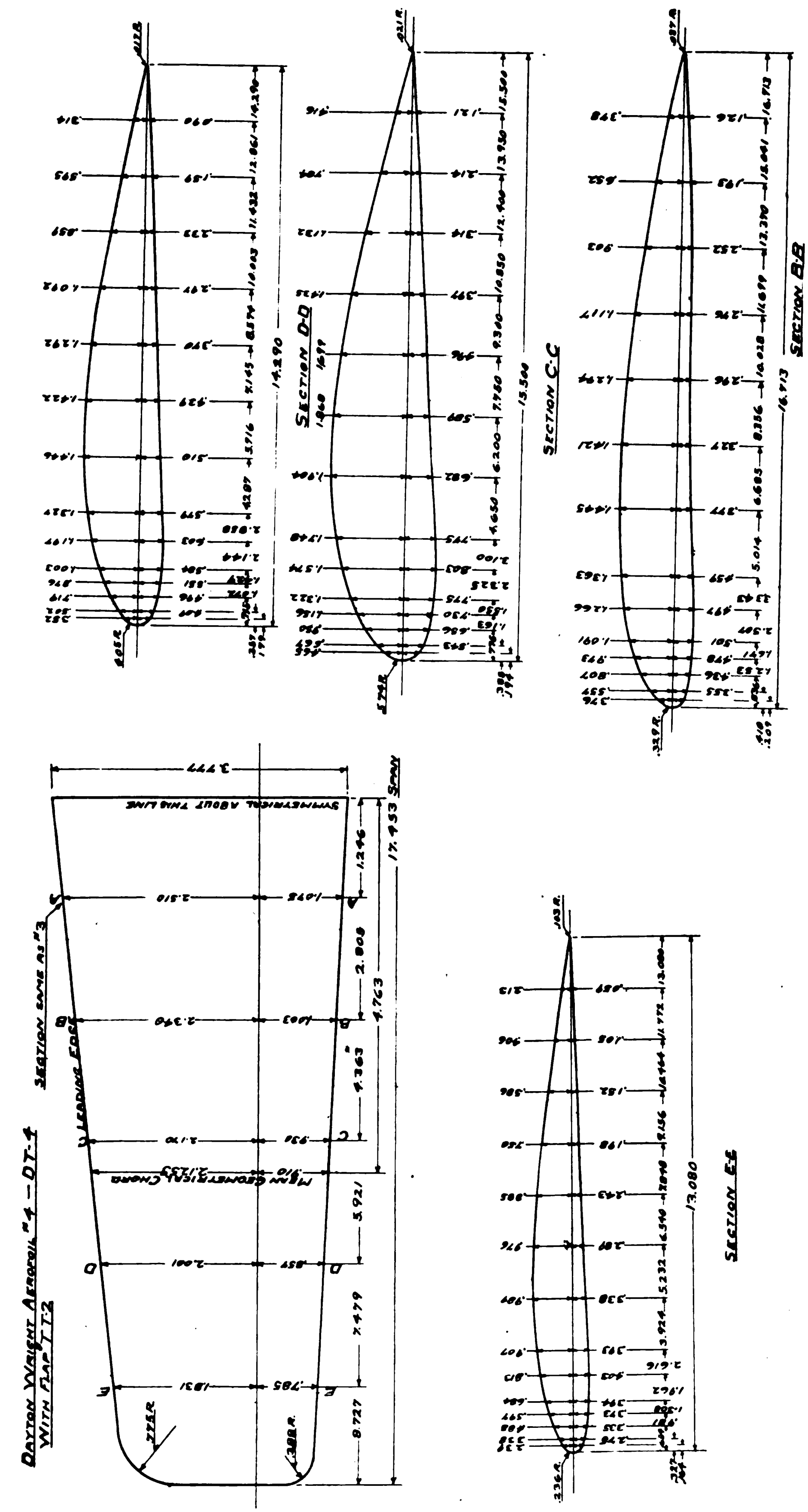

Dayton Wright Aerofoil #4 – DT-4
With Flap T T-2
Section same as #3
Leading Edge
Symmetrical about this line
Mean Geometrical Chord
17.453 Span
Section B-B
Section C-C
Section D-D
Section E-E

FIG. 12.

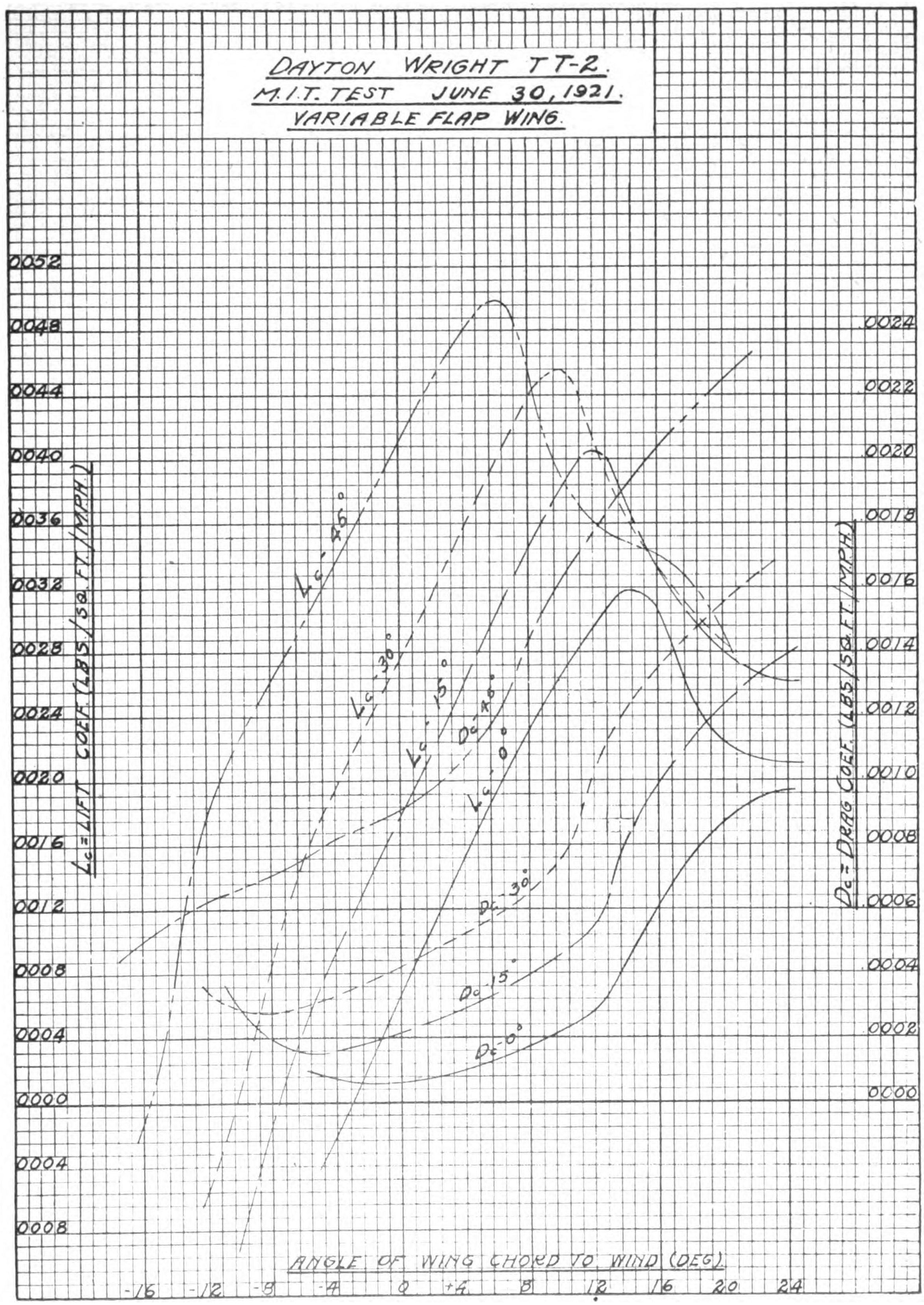
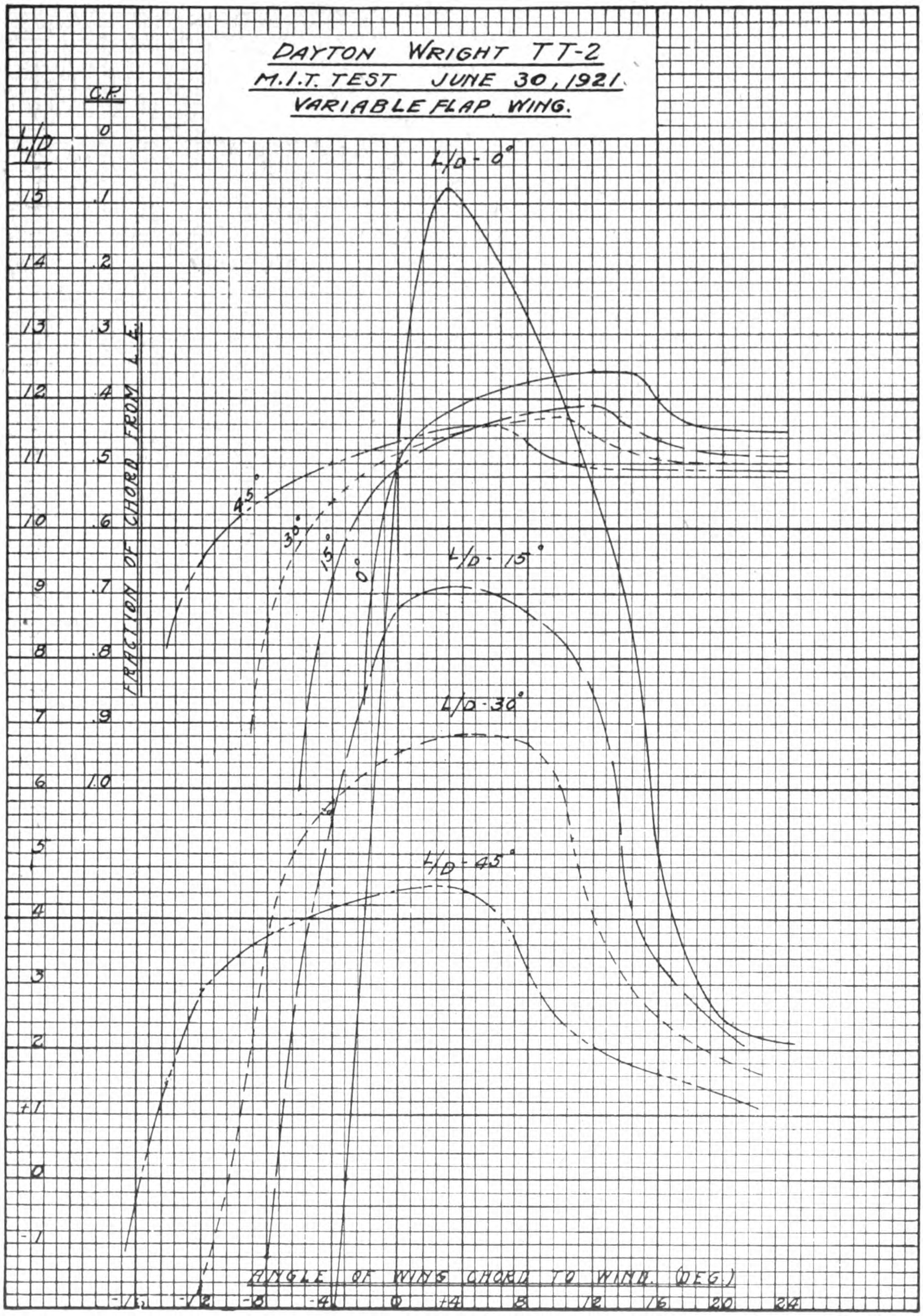
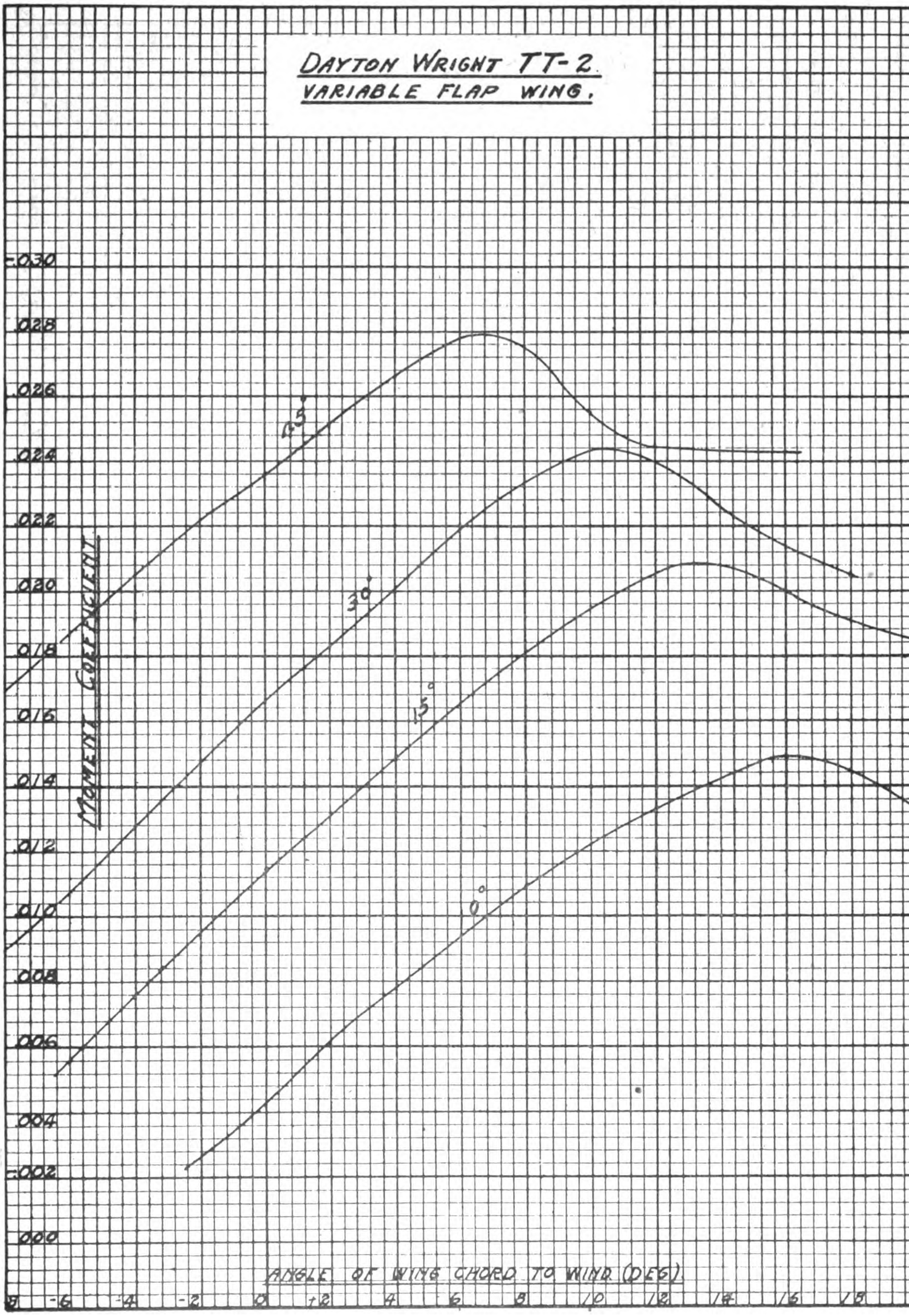

DAYTON WRIGHT TT-2.
M.I.T. TEST JUNE 30, 1921.
VARIABLE FLAP WING.
Lc = LIFT COEF. (LBS./SQ. FT./M.P.H.)
Dc = DRAG COEF. (LBS./SQ. FT./M.P.H.)
Lc - 45°
Lc - 30°
Lc - 15°
Lc - 0°
Dc - 45°
Dc - 30°
Dc - 15°
Dc - 0°
ANGLE OF WING CHORD TO WIND (DEG).
.0052
.0048
.0044
.0040
.0036
.0032
.0028
.0024
.0020
.0016
.0012
.0008
.0004
.0000
.0004
.0008
.0024
.0022
.0020
.0018
.0016
.0014
.0012
.0010
.0008
.0006
.0004
.0002
.0000
-16
-12
-8
-4
0
+4
8
12
16
20
24

Fig. 13.



DAYTON WRIGHT TT-2
M.I.T. TEST JUNE 30, 1921
VARIABLE FLAP WING.
L/D
C.P.
FRACTION OF CHORD FROM L.E.
L/D - 0°
L/D - 15°
L/D - 30°
L/D - 45°
45°
30°
15°
0°
ANGLE OF WING CHORD TO WIND (DEG.)
-16
-12
-8
-4
0
+4
8
12
16
20
24

FIG. 14.



DAYTON WRIGHT TT-2
VARIABLE FLAP WING.
MOMENT COEFFICIENT
.030
.028
.026
.024
.022
.020
.018
.016
.014
.012
.010
.008
.006
.004
.002
.000
45°
30°
15°
0°
ANGLE OF WING CHORD TO WIND (DEG).
-6
-4
-2
0
+2
4
6
8
10
12
14
16
18

FIG. 15.

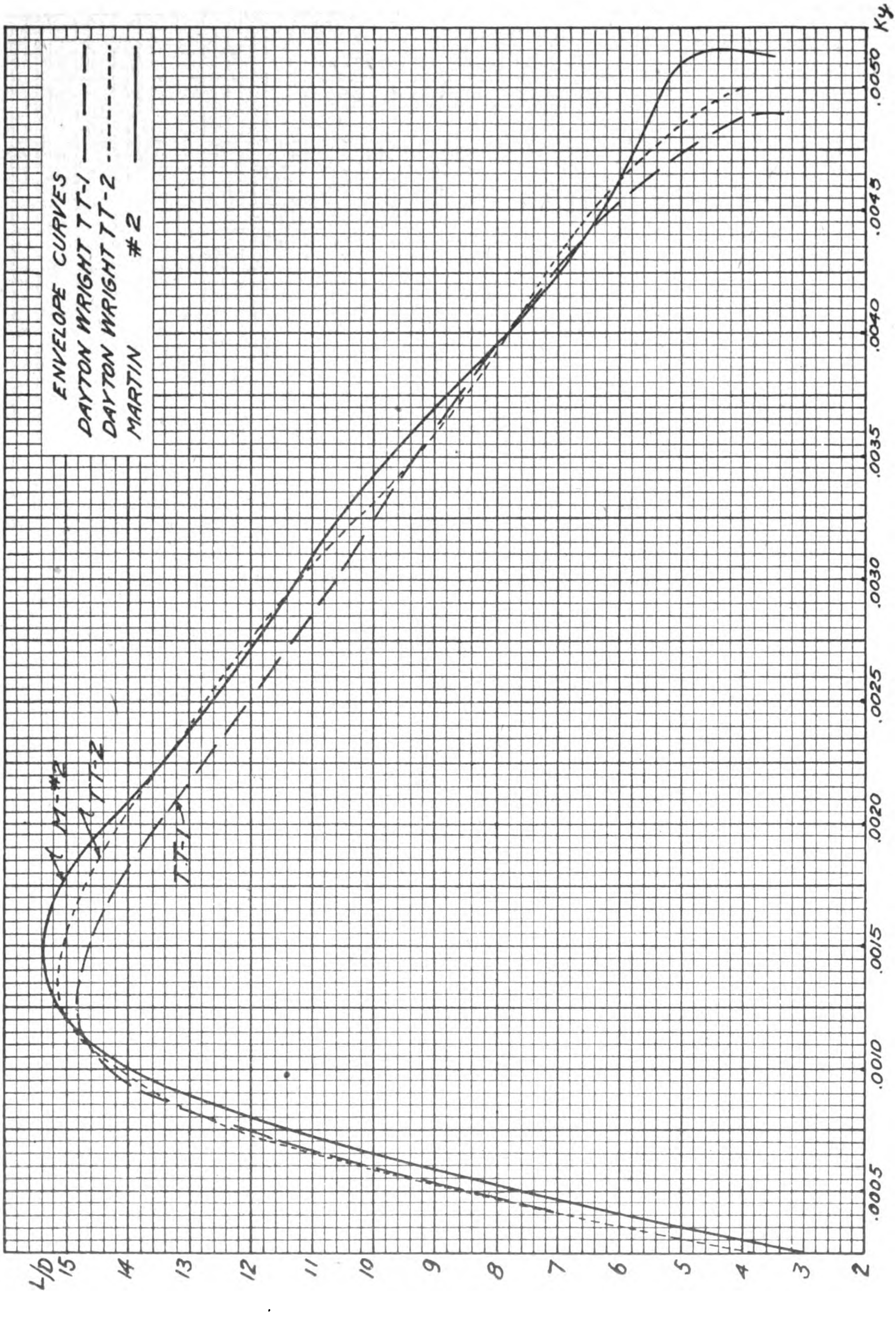

ENVELOPE CURVES
DAYTON WRIGHT T T-1
DAYTON WRIGHT T T-2
MARTIN #2
M-#2
TT-2
T.T-1
L/D
15
14
13
12
11
10
9
8
7
6
5
4
3
2
.0005
.0010
.0015
.0020
.0025
.0030
.0035
.0040
.0045
.0050
Ky

Fig. 16.

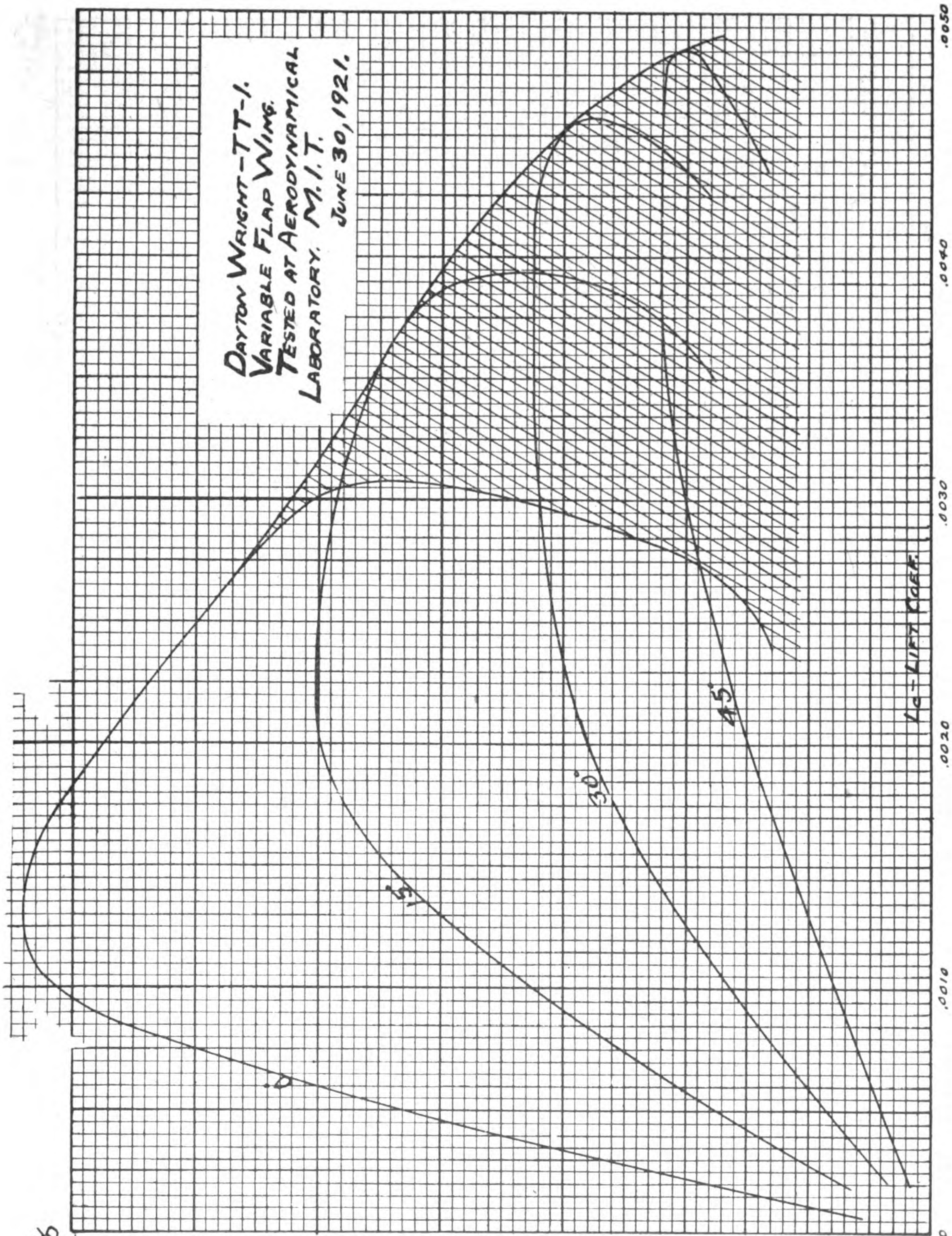

Dayton Wright-TT-1.
Variable Flap Wing.
Tested at Aerodynamical
Laboratory. M.I.T.
June 30, 1921.
L/D
Lc - Lift Coef.
0°
15°
30°
45°
.0010
.0020
.0030
.0040
.0050

Fig. 17.

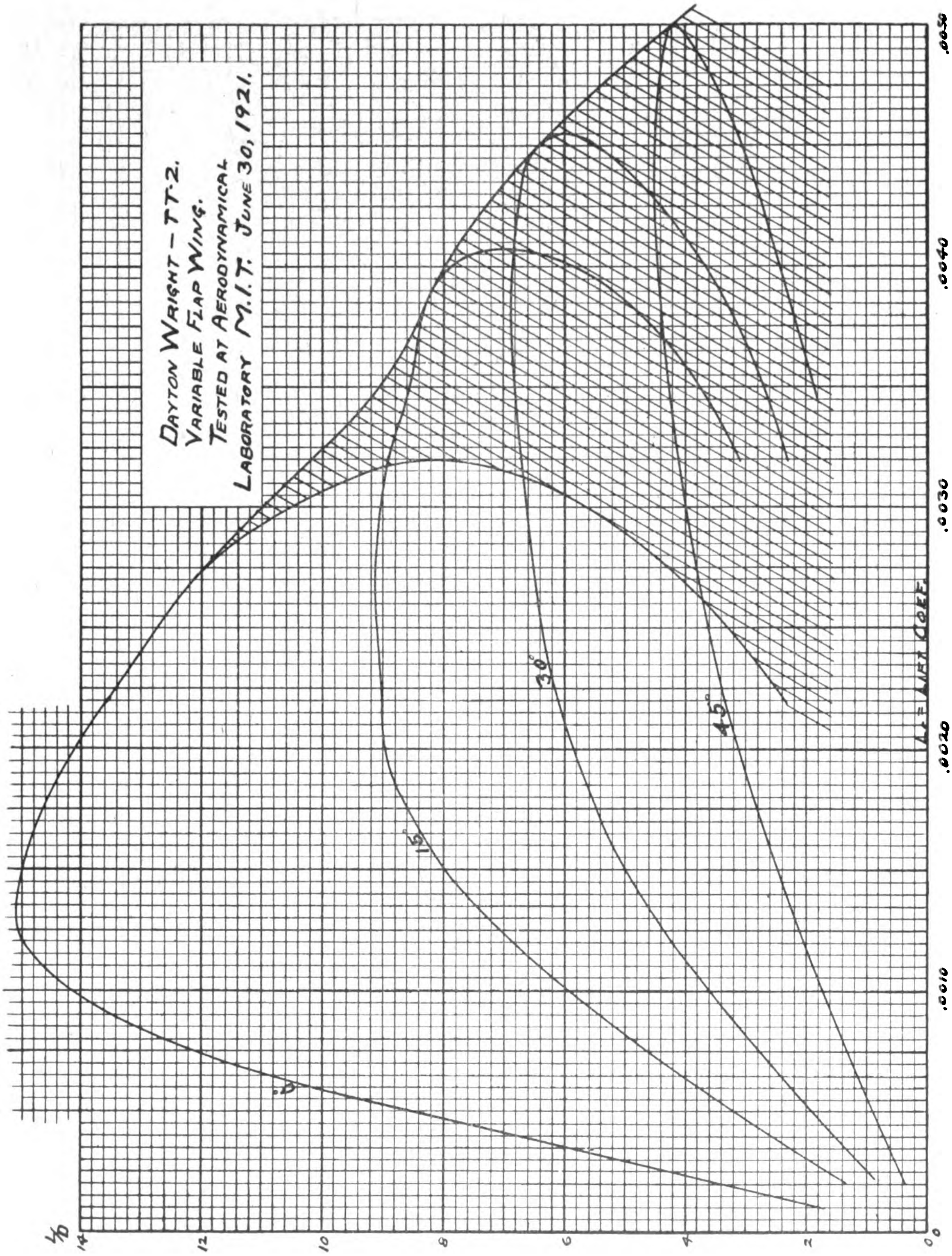

DAYTON WRIGHT - T.T-2.
VARIABLE FLAP WING.
TESTED AT AERODYNAMICAL
LABORATORY M.I.T. JUNE 30, 1921.
L/D
L = LIFT COEF.
0°
15°
30°
45°
14
12
10
8
6
4
2
0
0
.0010
.0020
.0030
.0040
.0050

FIG. 18.

FOR OFFICIAL USE ONLY
File D 52.41 / Curtiss / 25

McCOOK FIELD REPORT, SERIAL No. 177

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV — March 15, 1922 — No. 329

STANDARD ENGINE REPORT ON CURTISS MODEL C-6 AVIATION ENGINE RATED AT 160 HORSE-POWER AT 1750 REVOLUTIONS PER MINUTE

(POWER PLANT SECTION REPORT)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
November 28, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INDEX.

STANDARD ENGINE REPORT ON CURTISS MODEL C-6 AVIATION ENGINE RATED AT 160 HORSEPOWER AT 1,750 REVOLUTIONS PER MINUTE.

OBJECT.

The object of this test was to obtain complete information concerning the design and performance of the Curtiss 6-cylinder model C-6 aviation engine, rated at 160 horsepower at 1,750 revolutions per minute.

SUMMARY OF TEST RESULTS.

Normal brake horsepower at full throttle, 160.6 brake horsepower at 1,750 revolutions per minute.

Fuel consumption at normal horsepower, 0.500 pound per (actual) brake horsepower-hour.

Oil consumption at normal horsepower; 0.0157 pound per (actual) brake horsepower-hour.

Normal brake mean effective pressure, 126.9 pounds per square inch.

Total weight, dry, 448.5 pounds.

Weight, dry, per normal brake horsepower, 2.792 pounds.

CONCLUSIONS.

The engine is of a size adapted for training.

The design is not satisfactory for this service without changes to facilitate maintenance.

The performance of the engine was good.

As regards the suitability of this engine for service use, it is well to note that it completed, recently, a 50-hour endurance test, without any forced stops and with minor failures only.

DESCRIPTION OF THE CURTISS MODEL C-6 AVIATION ENGINE.

TYPE.

Name	Curtiss.
Model	C-6.
Serial number of engine tested	395 (mfrs).
Number of cylinders	6.
Arrangement	Vertical.
Drive	Direct.
Cooling	Water.
Cycle	Four stroke.
Fuel	Gasoline.
Tractor or pusher	Either.
Adapted to cannon	No.

MANUFACTURER.

Curtiss Aeroplane & Motor Corporation, Garden City, L. I.

CHARACTERISTIC FEATURES.

Steel cylinder liners with integral combustion chambers, screwed into aluminum head castings; detachable en bloc aluminum water jackets permitting cooling water in direct contact with the sides of cylinder barrel; two separate cam shafts; four directly driven valves per cylinder; aluminum alloy bearing bushings with white metal lining for main bearings and connecting rod bearings; wet sump; one Zenith double carburetor; and two Berkshire magnetos with provision for battery excitation in fully retarded position.

NOTE.—The construction of the Curtiss C-6 engine is exactly similar to that of the Curtiss C-12 engine except for a number of features noted below:

Crank case (see figs. 6 and 7):
- Crank-shaft bearings—
  - Material..........Aluminum alloy bearing bushing lined with white metal.
- Engine mounting lugs or flanges—
  - Number..........Eight.
  - Location..........Four on each side of upper case.
- Breathers—
  - Number..........Three.
  - Location..........In the right-hand upper corner of the transverse webs Nos. 2, 4, and 6.
  - Construction.....Cast in the web.
- Oil passages..........From mounting flange through No. 4 web to inside of case supplying oil to main bearings. From around No. 1 bearing to upper vertical shaft bearing and directly up to the top of the crank case supplying oil for the cam shafts.

Crank shaft (see fig. 8):
- Crank-shaft gear retained by one internal key.

Connecting rods (see fig. 9):
- Type..........Single.
- Big end bearing—
  - Material..........Aluminum alloy bearing bushing lined with white metal.

Drives (see figs. 11 and 19).

NOTE.—The photograph and drawing show clearly the construction, number of teeth, and rotation of the various drives. Bronze bushings are used for bearings throughout, except that the water pump shaft is equipped with a ball bearing to hold the thrust of the rotor due to the suction of the water lines. The cam-shaft gear is a skew bevel gear and is fastened to the exhaust cam shaft so that it is placed eccentrically within the cam-shaft gear housing.

Cooling system (see fig. 15):
- Water pump—
  - Number of outlets..........One.

Intake manifolds (see fig. 14):
- Number..........Two manifolds and one admission tee.

Carburetor (see fig. 14):
- Number..........One.
- Name..........Zenith.
- Model..........U. S. 52.
- Type..........Double.
- Manufacturer..........Zenith Carburetor Co., Detroit, Mich.
- Materials—
  - Body..........Aluminum alloy.
  - Nozzle..........Brass.
  - Jets..........Brass.
- Type of strainer..........Cylindrical wire mesh.
- Method of removing strainer..........Integral with brass cover cap.

This carburetor is exactly similar to those used on the 12-cylinder Liberty engine. A description of the Zenith model U. S. 52 carburetor is on page 23 of Engineering Division Report Serial No. 754.

Auxiliaries (see fig. 17):

Air pump—

Type	Single-acting, plunger.
Speed	1/14 crank-shaft speed.
Special features	A compensating piston to regulate the pressure required, by varying compression ratio.

Starter (see fig. 17).

The electric starting motor is mounted on the rear end of the crank case and is a 12-volt, four-pole, series-wound motor, single-wire system. In the gear case of the starting motor is a spur gear reduction and a Bendix drive device. This driving device meshes with the ring gear fastened to the propeller hub. The starter current is furnished by a 12-volt starting battery, and is controlled by an automatic solenoid switch. The "USL" starter furnished with this engine was a type G-27 (Mfr.'s No. 30). It was manufactured by the United States Lighting & Heating Corporation, Niagara Falls, N. Y.

METHOD OF TEST.

The engine was connected to an electric cradle dynamometer and the following runs were made in accordance with the standard method which is completely described in Engineering Division Report. Serial No. 1507:

Two full-power runs.

One friction horsepower and compression pressure run.

Two propeller load runs.

One-hour fuel and oil consumption run.

One mixture control run.

One water circulation run through the engine.

One water pump capacity run with free outlet.

Trials to determine starting torque with engine hot and cold.

The temperature of the oil supplied to the bearings was taken between the pressure pump and the main bearings at a flange connection on the left side of the upper half of the crankcase at No. 4 web.

The oil consumption was obtained during the one-hour run. The crank case was nearly filled with oil and the engine was warmed up. Before starting this test the position of the oil gauge was marked. After the test sufficient oil was added to bring the gauge back to this mark. The amount of oil added was taken as the oil consumption for that period.

This engine was given a 50-hour endurance test on the completion of the dynamometer runs, the results of which are incorporated in Air Service Information Circular, Vol. III, No. 272.

RESULTS OF TEST.

The test results which appear in this report were obtained from manufacturer's engine No. 395. It must be borne in mind that in laboratory tests it is possible to operate an engine under more favorable conditions than in actual service. The engine under consideration, when installed in an airplane, and run by the average pilot, will not develop the power nor have the fuel economy which is recorded in the tables and curves in this report. It will be noted that the air temperatures during the various runs averaged 70° F. and, therefore, the power results are perhaps a little lower than would have been obtained at the standard air temperature of 60° F. The power results are not corrected for temperature, as no reliable method is at present available.

The performance tables are on pages 5 to 8. The performance curves are shown in figures 21, 22, 23, and 24.

Referring to the table of efficiency factors on page 5, the air standard efficiency is the theoretical thermal efficiency based on the compression ratio and computed from the following formula, where E is the efficiency and R the compression ratio:

$$E=1-\left(\frac{1}{R}\right)0.408$$

The relative indicated efficiency is the ratio of the indicated thermal efficiency to the air standard efficiency.

The relative brake efficiency is the ratio of the brake thermal efficiency to the air standard efficiency.

OBSERVATIONS ON TEST.

The performance of this engine during the test was very good, and no trouble of any kind was experienced in operation of the engine. The vibration was about what might be expected from a 6-cylinder engine of this type, but under laboratory conditions it is impossible to obtain reliable observations in regard to vibration as the engine is very rigidly mounted.

Slight oil leakage was noted at the upper end of the housing for the vertical drive to the cam shaft and at the magneto drive-gear housing.

INSPECTION AFTER TEST.

At the completion of the standard engine tests the Curtiss model C–6 engine was completely disassembled for inspection. The following is a report on the condition of the various parts:

CRANK SHAFT.

Journals Nos. 1, 3, and 5 had slight scores in fillets. All crank pins showed slight uneven wear and circumferential scoring. The taper at the front end of shaft showed poor lapping, some burning, scores along whole length and a rust deposit at the large end. The front end of No. 7 journal was scored probably by the oil ring.

PROPELLER HUB.

The remarks about condition of taper on crank shaft also apply to the bore of the propeller hub.

BEARINGS.

The bearings were in exceptionally good condition. The white metal in the crank-shaft bearings was slightly worn away around the oil holes. The connecting-rod bearings showed very little wear.

PISTONS.

There was only a moderate deposit of carbon on the top of the piston and practically none inside. The skirt

showed wear on the two sides away from the piston pin bosses. Pistons Nos. 1 and 5 had deep circumferential scratches on the skirt.

CAM SHAFT.

The rear part of the right cam shaft showed poor machining. There was slight wear on the surface of the cams. The most noticeable feature was the deposit of rust on all steel parts of the cam-shaft assembly.

GEARS.

There was a burr on inside of gear teeth of cam-shaft drive gear. The crank-shaft gear showed signs of slight bottoming. The teeth of the ratchet gear for hand starting were badly burred.

VALVES.

See figure 18. The intake valves had a heavy deposit of carbon. The following valves leaked when tested with gasoline:

Exhaust:[1]—Nos. 3, 5, 7, 9, 11, 13, 15, 17, 21, 23.

Intake:[1]—No. 22.

All other parts showed normal signs of wear incident to a test of this nature. Some water was found in the oil in the crank case and in the cam-shaft housing.

ANALYSIS.

DESIGN.

The general design is good and the engine assembly presents a compact, clean-cut appearance. The outstanding feature is the en bloc cylinder construction, which permits cooling water in direct contact with the steel liner or cylinder sleeve, except around the combustion chamber. The method of securing good contact of the liner in the cylinder head proper is particularly good. This contact is made by drawing up the integral stud, in the head of the cylinder sleeve, with a nut inside of the water jacket. To make this type of construction watertight is a difficult problem. A little water was found in the oil in the crank case and the steel parts of the cam-shaft housing were rusted. The leak could not be detected when the water jacket was tested for leakage with the engine cold. After the 50-hour test the Welsh plugs, in the aluminum cylinder jacket, were found to leak water.

The use of aluminum bearing bushings lined with white metal for connecting rod and crank-shaft main bearings was exceptionally successful.

The four valves are so located in the cylinder head that they can not be removed without first removing the valve guides. This makes valve grinding very difficult.

Oil from around No. 1 main bearing is taken to the cam-shaft bearings. An oil hole in the rear cam-shaft bearing support registers with a hole in the cylinder head. As there is no locating dowel pin, this support can be reversed, in which case the cam-shaft bearings will get no oil. This should be corrected by the addition of a dowel pin in the bearing support.

Bronze bushings are used for bearings for the various drive shafts, with the exception of the water pump shaft. These bronze bearings are apt to seize at high engine speeds. White-metal lining is better than plain bronze but ball bearings are best.

All the thrust of the cam shaft is taken by No. 1 bearing support. This is held by two small studs, which do not appear strong enough to carry the load.

ADAPTABILITY TO PRODUCTION.

The engine presents no features which can not be easily handled in quantity production.

PERFORMANCE.

The performance of the engine on the dynamometer stand was good. The full-power curve had not peaked at 2,100 revolutions per minute, at which speed the engine developed 190 brake horsepower. The brake mean effective pressure at normal speed of 126.9 pounds per square inch was rather high and was maintained fairly constant, thus indicating a high volumetric efficiency throughout the speed range.

The weight, dry, of 2.792 pounds per normal brake horsepower is not very good, but is due to the use of a 6-cylinder construction. The specific fuel consumption with full throttle was good and was practically constant at 0.500 pound per horsepower at all speeds from 1,200 to 2,100 revolutions per minute. The specific fuel consumption on propeller load operation was less than at full throttle operation from 1,400 to 1,800 revolutions per minute, having its lowest consumption of 0.470 pound per horsepower hour at 1,600 revolutions per minute. At speeds below 1,400 revolutions per minute the specific fuel consumption increased rapidly with reduction of speed. Since an engine in service operates most frequently at partial throttle, the conditions indicated on propeller load from 1,800 to 1,400 revolutions per minute should give very satisfactory results. The oil consumption of 0.0157 pound per (actual) normal brake horsepower hour was excellent.

ADAPTABILITY TO AIR PLANE.

This engine provides for straightforward mounting, requiring only two engine bed timbers. It is possible to slide the engine in and out on the bed timbers. The head resistance area is not great.

ACCESSIBILITY.

The accessibility of all parts and accessories for adjustment and inspection is exceptionally good. The carburetor and magnetos can be reached for adjustment through openings at the sides of the engine cowling. The spark plugs are placed in the sides of the cylinder and are easily reached for replacements. The water pump and the adjustable oil pressure relief valve can be easily reached for adjustments through openings properly located in the engine cowling.

MAINTENANCE.

The construction of the engine is such that overhauling can not be done without a considerable expenditure of time as compared with other engines. For instance, the valves can not be ground without removal of the valve guides, which is an operation requiring special tools and more than average care. Many of the aluminum flanges on the engine are so thin as to be subject to breakage in handling or in drawing up on the bolts.

[1] The valves are numbered from 1 to 24, starting from the rear of the engine. The exhaust valves have odd numbers and the intake valves have even numbers.

WEIGHTS OF CURTISS MODEL C-6 ENGINE AND PARTS.

	Weight, pounds.	Per cent of total.
Crank-case group, complete, with bearings, studs, nuts, and breathers, including:		
1 upper half.....pounds.. 69.5		
1 lower half.....do.... 37.5		
Total.....	107.0	23.86
Crank-shaft group, complete, with gear, thrust bearing, oil tubes, etc.....	58.5	13.03
Propeller hub assembly, complete.....	18.0	4.02
Connecting-rod group, including 6 connecting-rod assemblies averaging 3.4 pounds each.....	20.5	4.57
Piston group, including 6 piston assemblies, complete, with rings and pin averaging 2.3 pounds each.....	13.8	3.08
Cylinder group, including 6 cylinder assemblies (in block), complete, with valves, valve springs, and valve guides.....	107.0	23.86
Driving-gear group, including:		
Cam-shaft driveshaft and housing, pounds.. 2.4		
Magneto brackets and bolts, magneto couplings, upper and lower vertical drives and housing.....pounds.. 14.9		
Oil drive.....do.... .9		
Starter driving gear.....do.... 7.5		
Total.....	25.7	5.73
Cam-shaft group, including:		
2 cam shafts, complete, with gears and bearings.....pounds.. 14.0		
1 cam-shaft housing, complete.....do.... 7.6		
12 cam followers.....do.... 3.6		
Total.....	25.2	5.62
Lubrication group, including:		
1 oil-pump assembly.....pounds.. 6.2		
Oil manifold and piping.....do.... 2.6		
Total.....	8.8	1.96
Cooling system group, including:		
Water pump assembly.....pounds.. 3.8		
Water manifolds.....do.... 4.0		
Total.....	7.8	1.74
Carburetor and intake group, including:		
1 double carburetor assembly.....pounds.. 6.8		
2 intake manifolds and admission tee.....pounds.. 11.9		
Total.....	18.7	4.17
Ignition group, including:		
2 magneto assemblies.....pounds.. 31.0		
Ignition wires and headers with distributor covers.....pounds.. 4.5		
Spark plugs.....do.... 2.0		
Total.....	37.5	8.36
Total weight, without auxiliaries.....	448.5	100.00
Auxiliaries:		
1 battery for starting.....pounds.. 10.5		
1 air pump.....do.... 3.0		
1 starter, complete.....do.... 19.5		
Total.....	33.0	....
Total weight of engine, with auxiliaries.....	481.5	....
Weight of water in engine.....	18.5	....

TABLE OF DIMENSIONS.

NOTE.—All dimensions not shown are the same as the Curtiss model C-12 engine.

General:
- Bore.....4.500 in.
- Stroke.....6.000 in.
- Compression ratio.....5.4:1.
- Gear ratio.....Direct drive.
- Rotation of propeller (facing propeller).....Counterclockwise.
- Total piston displacement.....572.4 cu. in.
- Approximate head resistance area.....3.92 sq. ft.
- Firing order.....1-5-3-6-2-4.
- Method of numbering cylinders.....From the gear end.

Crank case:
- Distance between centers of cylinders—
  - Nos. 1-2.....5.187 in.
  - Nos. 2-3.....6.000 in.
  - Nos. 3-4.....5.187 in.
  - Nos. 4-5.....6.000 in.
  - Nos. 5-6.....5.187 in.
- Diameter main bearing studs—
  - Inside rows.....7/16 in.
  - Outside rows.....3/8 in.
- Capacity of oil sump.....5 U. S. gallons.
- Main crank-shaft bearings—

No.	Diameter.	Length.	Diametral clearance.	End clearance.	Projected area.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Square inches.*
1.....	2.752	2.031	0.002	0.031	5.590
2-4-6.....	2.752	1.375	.002	.125	3.784
3-5.....	2.752	2.188	.002	.125	6.020
7.....	2.752	3.094	.002	.312	8.515
8.....	2.752	1.750	.002	....	4.816

- Engine hold-down bolts—
  - Number.....8.
  - Diameter.....3/8 in.

Crank shaft:

No.	Outside diameter.	Length.	Diameter, bore.
Main journals—	*Inches.*	*Inches.*	*Inches.*
1.....	2.750	2.062	2.250
2-4-6.....	2.750	1.500	2.250
3-5.....	2.750	2.313	2.250
7.....	2.750	3.406	2.250
8.....	2.750	2.062	2.250
Crank pins—			
1-2-3-4-5-6.....	2.500	2.145	1.938

- Crank cheeks.....Width, 3.500 in.; thickness, 0.750 in.
- Thrust bearing—
  - Type.....Single row, ball.
  - Number of balls.....10.
  - Diameter of balls.....0.625 in.
  - Diameter of ball circle.....4.000 in.
  - Manufacturer and number.....Hess-Bright No. 6215.
- Length of shaft from front end to first crank cheek.....17.312 in.

Propeller hub:
- Diameter hub body.....2.625 in.
- Length between flanges—
  - Maximum.....6.000 in.
  - Minimum.....4.625 in.
- Diameter bolt circle.....6.750 in.
- Number of bolts.....8.
- Diameter of bolts.....0.500 in.
- Area of bearing surface on shaft taper.....43.50 sq. in.

Connecting rods:
- Length, center to center.....10.000 in.
- Rod-stroke ratio.....1.667:1.
- Piston pin bushing—
  - Length.....1.562 in.
  - Diameter, inside.....1.126 in.
  - Projected area.....1.757 sq. in.
  - Clearance to pin.....0.001 in.
  - End play of rod on pin.....0.188 in.

Connecting rods—Continued.
- Big end bearing—
  - Length .... 2.125 in.
  - Diameter .... 2.502 in.
  - Number of bolts .... 4.
  - Minimum diameter of shank (bolts) .... 0.311 in.
  - Thread (bolts) .... 3/8", 24 threads per inch.
- Clearance on crank pin—
  - Diametral .... 0.002 in.
  - End .... 0.020 in.
- Projected area on crank pin .... 5.315 sq. in.

Cylinders:
- Bore .... 4.500 in.
- Stroke .... 6.000 in.
- Stroke-bore ratio .... 1.333:1.
- Piston displacement per cylinder .... 95.40 cu. in.
- Total piston displacement of engine .... 572.4 cu. in.
- Compression volume of cylinder .... 21.68 cu. in.
- Total volume of cylinder .... 117.08 cu. in.
- Compression ratio .... 5.4:1.
- Per cent compression .... 18.52.

Cam shaft:
- Outside diameter .... 0.975 in.
- Bore diameter .... 0.688 in.

Valve timing:

	Designed.	Actual.
Inlet—		
Opens	15° early	18° early.
Closes	26° late	24° late.
Exhaust—		
Opens	50° early	46° early.
Closes	5° late	11° late.

Carburetor:
- Number .... 1 double.
- Material, body .... Aluminum alloy.
- Rated size .... 52 mm.
- Diameter at the flange inside .... 1⅞ in.
- Chokes, diameter .... 1.106 in.
- Metering jets, material .... Brass.
- Diameter, main .... 54 drill size.
- Diameter, compensator .... 52 drill size.

96725—22— -2

Efficiency factors for Curtiss Model C-6 aviation engine at normal speed of 1,750 R. P. M.

Cubic inches of piston displacement per brake horsepower		3.565
Brake horsepower per cubic inch of piston displacement		.281
Brake horsepower per cubic foot of piston displacement		485.0
Brake horsepower per square foot of piston area		242.5
Piston speed in feet per minute		1,750
Indicated mean effective pressure	pounds per square inch	145.3
Friction mean effective pressure	do	18.4
Brake thermal efficiency [1]	per cent	24.20
Indicated thermal efficiency [1]	do	27.72
Air standard efficiency	do	49.74
Relative indicated efficiency	do	55.75
Relative brake efficiency	do	48.67
Mechanical efficiency	do	87.25
Weight per cubic inch of piston displacement	pounds	.784

POWER PLANT WEIGHT BY CLASS OF SERVICE (POUNDS).[2]

Weight factors.	Pursuit.[3]	Two-place.[4]	Training.[5]
Engine weight, dry	452.5	452.5	452.5
Power plant constant weight	112.1	112.1	112.1
Cooling system	104.3	104.3	104.3
Tankage	58.4	95.4	73.2
Fuel	156.6	263.1	200.5
Oil	36.7	36.7	36.7
Total	920.6	1,067.1	979.3
Per horsepower	5.732	6.645	6.098

Altitude.	Horse-power (see curve, fig. 23.)	Fuel consumption (pounds per hour).
Sea level	160.6	80.3
10,000 feet	104.7	56.5
15,000 feet	80.6	46.6

[1] Heat content of fuel, 21,000 British thermal units per pound.
[2] For explanation of items, etc., see Engineering Division Report, Serial No. 1506, p. 25a et seq.
[3] ½ hour at sea level, 2½ hours at 15,000 feet.
[4] ¾ hour at sea level, 4 hours at 10,000 feet.
[5] 2½ hours at sea level.

FIRST FULL-POWER RUN.

Positions of altitude control.[1]	R. p. m.	Actual—		Corrected—			Water.		Oil.			Carb. air temp. °F.	Carb. vac., in. hg.	Man. vac., in. hg.	Fuel cons.		
		Brake load, lb.	Brake horse-power.	Torque, lb.-ft.	Horse-power.	B. m. e. p., lb. per sq. in.	Temp. °F. In.	Temp. °F. Out.	Temp. °F. Sump.	Temp. °F. Bearings.	Press., lb. per sq. in.				Sec. for 3 lb.	Lb. per hp.-hr.	Lb. per hr.
3	1,250	267	111.3	476.7	113.5	125.6	145	160	72	132	82	75	0.5	0.5	176.2	0.551	61.3
3	1,350	267	120.2	476.7	122.6	125.6	141	157	72	135	83	76	.6	.6	187.0	.481	57.8
3	1,450	267	129.1	476.7	131.6	125.6	143	161	73	139	88	76	.7	.7	155.8	.537	69.3
3	1,550	270	139.5	482.2	142.3	127.1	144	161	72	140	89	76	.8	.9	161.6	.479	66.8
2	1,670	273	152.0	487.5	155.1	128.5	138	155	72	145	88	75	1.0	1.1	143.4	.496	75.4
1.5	1,770	270	159.4	482.2	162.6	127.1	145	162	75	149	88	74	1.1	1.2	134.4	.504	80.4
1.5	1,870	266	165.7	475.0	169.1	125.2	142	158	77	151	90	74	1.3	1.4	129.6	.503	83.3
0	1,990	260	172.5	464.5	175.9	122.4	145	160	77	153	92	73	1.4	1.5	124.0	.505	87.2
0	2,070	255	175.9	455.4	179.5	120.0	143	158	77	159	91	74	1.5	1.6	118.6	.517	91.0

Average barometer, 29.33 in. hg.

SECOND FULL-POWER RUN.

Positions of altitude control.[1]	R. p. m.	Actual—		Corrected—			Water.		Oil.			Carb. air temp. °F.	Carb. vac., in. hg.	Man. vac., in. hg.	Fuel cons.		
		Brake load, lb.	Brake horse-power.	Torque, lb.-ft.	Horse-power.	B. m. e. p., lb. per sq. in.	Temp. °F. In.	Temp. °F. Out.	Temp. °F. Sump.	Temp. °F. Bearings.	Press., lb. per sq. in.				Sec. for 3 lb.	Lb. per hp.-hr.	Lb. per hr.
4.5	1,250	267	111.2	476.8	113.4	125.6	141	162	72	127	89	75	0.6	0.6	180.4	0.539	59.9
3	1,350	265	119.2	473.1	121.5	124.6	144	165	72	132	89	76	.6	.6	186.2	.487	58.1
3	1,470	268	131.3	478.5	133.9	126.1	141	163	72	137	91	76	.8	.8	155.6	.529	69.5
3	1,540	266	136.6	475.0	139.3	125.2	140	158	72	139	91	76	.8	.9	169.0	.468	63.9
2	1,670	274	152.5	489.1	155.5	128.8	144	163	72	142	91	75	1.0	1.1	143.2	.495	75.5
2	1,770	270	159.3	482.0	162.5	127.0	142	159	75	145	92	75	1.1	1.2	134.8	.503	80.2
1.5	1,870	268	167.0	478.5	170.4	126.1	143	158	75	148	93	75	1.3	1.4	128.8	.502	83.9
0	1,970	262	172.1	467.7	175.5	123.2	144	160	77	151	93	74	1.4	1.5	124.8	.503	86.6
0	2,060	255	175.2	455.3	178.7	119.9	142	158	77	152	94	73	1.5	1.6	121.2	.509	89.1

[1] Altitude control has 10 equal divisions: 0=full rich position; 10=full lean position.

Average barometer, 29.33 in. hg.

FIRST PROPELLER LOAD RUN.

R. p. m.	Actual—		Corrected—		Water.		Oil.			Carb. air temp. °F.	Carb. vac., in. hg.	Man. vac., in. hg.	Fuel cons.		
	Brake load, lb.	Brake horse-power.	Torque, lb.-ft.	Horse-power.	Temp. °F. In.	Temp. °F. Out.	Temp. °F. Sump.	Temp. °F. Bearings.	Press., lb. per sq. in.				Sec. for 3 lb.	Lb. per hp.-hr.	Lb. per hr.
1,770	269	158.7	480.6	161.8	145	159	75	136	103	73	1.1	1.2	136.4	0.499	79.2
1,660	240	132.8	428.5	135.5	141	158	73	142	88	73	.7	3.7	172.2	.473	62.8
1,550	212	109.5	378.5	111.7	145	161	73	143	82	74	.5	5.8	204.4	.483	52.9
1,450	184	88.9	328.4	90.7	145	160	73	141	78	74	.4	7.8	237.6	.511	45.4
1,340	161	72.0	287.5	73.5	147	162	72	138	77	76	.3	9.6	279.6	.537	38.6
1,240	138	57.1	246.4	58.3	144	158	72	133	78	77	.2	11.2	325.8	.581	33.2

Average barometer, 29.33 in. hg.

SECOND PROPELLER LOAD RUN.

R. p. m.	Actual—		Corrected—		Water.		Oil.			Carb. air temp. °F.	Carb. vac., in. hg.	Man. vac., in. hg.	Fuel cons.		
	Brake load, lb.	Brake horse-power.	Torque, lb.-ft.	Horse-power.	Temp. °F. In.	Temp. °F. Out.	Temp. °F. Sump.	Temp. °F. Bearings.	Press., lb. per sq. in.				Sec. for 3 lb.	Lb. per hp.-hr.	Lb. per hr.
1,790	271	161.7	483.1	164.6	145	161	81	135	104	61	1.1	1.2	134.2	0.498	80.5
1,660	238	131.7	424.4	134.1	143	158	77	142	88	60	.8	3.9	174.2	.471	62.0
1,550	208	107.5	370.9	109.5	144	160	77	143	81	60	.6	6.0	207.4	.485	52.1
1,460	184	89.6	328.0	91.3	144	159	77	141	78	61	.4	7.7	238.8	.505	45.3
1,340	162	72.4	288.8	73.7	146	160	75	137	78	62	.3	9.7	276.0	.541	39.2
1,240	131	54.2	233.3	55.2	144	157	73	132	78	63	.2	11.7	287.8	.693	37.6

Average barometer, 29.39 in. hg.

NOTE.—Altitude control set 0.2 full lean position for both runs.

ONE-HOUR FUEL AND OIL CONSUMPTION RUN.

R.p.m.	Actual— Brake load, lb.	Actual— Brake horse-power	Corrected— Torque, lb.-ft.	Corrected— Horse-power.	Corrected— B. m. e. p., lb. per sq. in.	Water Temp. °F. In.	Water Temp. °F. Out.	Oil. Temp. °F. Sump.	Oil. Temp. °F. Bear-ings.	Oil. Press., lb. per sq. in.	Carb. air temp. °F.	Carb. vac., in. hg.	Man. vac., in. hg.	Fuel cons. Lb. for 5 min.	Fuel cons. Lb. per hp.-hr.	Oil cons. Lb. for 60 min.	Oil cons. Lb. per hp.-hr.
....	268	....	477.3	....	125.7	141	156	80	135	108	62	1.1	1.2	....	....	....	....
1,782	271	160.9	482.4	163.6	127.1	146	161	77	142	92	62	1.1	1.2	6.75	0.503	....	....
1,770	272	160.4	484.1	163.1	127.6	144	159	77	148	85	62	1.1	1.2	6.75	.505	....	....
1,752	272	158.8	484.1	161.5	127.6	144	160	77	148	84	62	1.1	1.2	6.50	.492	....	....
1,766	272	160.2	484.1	162.8	127.6	145	161	77	149	83	62	1.1	1.2	6.75	.506	....	....
1,762	272	159.6	484.1	162.3	127.6	144	160	77	149	82	62	1.1	1.2	6.50	.489	....	....
1,762	271	159.2	482.4	161.8	127.1	145	161	77	150	80	62	1.1	1.2	6.50	.490	....	....
1,766	272	160.1	484.1	162.7	127.6	142	158	77	150	80	62	1.1	1.2	6.75	.506	....	....
1,768	271	159.8	482.4	162.5	127.1	143	159	77	150	80	62	1.1	1.2	6.50	.488	....	....
1,760	271	159.1	482.4	161.7	127.1	144	160	77	150	81	62	1.1	1.2	6.75	.509	....	....
1,766	271	159.5	482.4	162.2	127.1	143	160	77	150	81	62	1.1	1.2	6.50	.489	....	....
1,756	271	158.5	482.4	161.3	127.1	143	159	77	150	81	62	1.1	1.2	6.50	.492	....	....
1,744	270	157.0	480.5	159.6	126.6	143	159	77	149	81	62	1.1	1.2	6.75	.516	....	....
AVERAGE RESULTS FOR ONE HOUR.																	
1,763	271	159.2	482.4	161.8	127.1	144	160	77	148	84	62	1.1	1.2	[1] 79.50	0.500	2.50	0.0157

[1] Total for 60 minutes.

NOTE.—Altitude control set 0.2 full lean position.
Average barometer, 29.42 in. hg.
Data for all runs:
Length of brake arm, 21 inches.
Kind of oil used, 50 per cent castor, 50 per cent Mobiloil "B".
Specific gravity of gasoline, 0.710 at 60°F.

MIXTURE CONTROL RUN.[1]

FULL RICH SETTING.

Positions of altitude control.	R. p. m.	Actual— Brake load lb.	Actual— Brake horse-power.	Corrected— Torque lb.-ft.	Corrected— Horse-power.	Corrected— B. m. e. p. lb. per sq. in.	Water. Temp. °F. In.	Water. Temp. °F. Out.	Oil. Temp. °F. Sump.	Oil. Temp. °F. Bear-ings.	Oil. Press., lb. per sq. in.	Carb. air temp. °F.	Man. vac. in. hg.	Carb. vac. in. hg.	Float cham-ber vac. in. water.	Gas. cons. Sec. for 3 lb.	Gas. cons. Lb. hp. hr.
Full rich....	1,780	274	162.5	491.1	166.4	129.4	145	160	75	134	103	70	1.2	1.1	1.4	129.2	0.515
Do......	1,570	216	113.1	387.0	115.7	102.0	146	162	73	136	89	70	5.8	.5	1.2	181.0	.528
Do......	1,250	140	58.3	250.9	59.7	66.1	146	158	72	132	73	70	11.3	.3	.9	303.2	.611
BEST SETTING.																	
(2)	1,790	273	162.9	489.4	166.8	128.9	145	160	77	145	85	70	1.2	1.1	1.6	131.2	0.505
1.5 div......	1,560	212	110.3	379.9	112.9	100.1	144	160	75	140	81	70	5.8	.5	1.7	219.6	.446
Full lean....	1,240	140	57.9	250.9	59.3	66.1	148	160	72	129	81	70	10.1	.3	2.0	363.4	.513
FULL LEAN SETTING.																	
Full lean....	1,770	215	126.8	385.3	129.9	101.5	150	162	75	147	84	70	1.2	1.1	5.4	172.6	0.494
Do......	(3)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Do......	1,290	137	58.9	245.5	60.3	64.7	148	160	72	126	84	70	10.2	.2	2.0	361.1	.508

[1] Speed and load adjusted as for propeller load operation.
[2] Just cracked open.
[3] Could not run at 1,550 r. p. m. as engine missed and back-fired.

Average barometer, 29.22 in. hg.

FRICTION HORSEPOWER AND COMPRESSION PRESSURE RUN.

Engine, r. p. m.	Corrected engine, b. h. p.[1]	Friction load, lb.	Friction horsepower.	Per cent mech. eff.	Temperatures °F. Water. In.	Temperatures °F. Water. Out.	Temperatures °F. Oil. Sump.	Temperatures °F. Oil. Bearings.	Cylinder No.	Comp. Press., lb. per sq. in.[2]	B. m. e. p., lb. per sq. in.
1,250	113.5	31	12.9	89.8	145	147	93	143	1	100	14.3
1,350	123.5	33	14.9	89.3	145	147	97	143	2	100	15.3
1,450	133.0	35	16.9	88.7	145	147	99	143	3	101	16.1
1,550	142.5	37	19.1	88.2	145	147	99	145	4	100	17.0
1,650	152.0	39	21.5	87.6	145	147	100	146	5	102	18.0
1,750	160.5	40	23.3	87.3	145	147	102	146	6	100	18.4
1,850	168.0	42	25.9	86.7	145	147	104	146	....	....	19.4
1,950	174.0	44	28.6	85.9	145	147	99	148	....	....	20.3
2,050	178.3	47	32.1	84.8	145	147	95	149	....	....	21.7

[1] Corrected engine brake horsepower taken from curve in fig. 21.
[2] Compression pressure taken at 120 revolutions per minute.

Average barometer, 29.33 in. hg.
Average air temperature, 72° F.

STARTING TORQUE.

Engine cold. Throttle position.	Engine cold. Starting torque, lb.-ft. 1	2	3	Average.	Engine warm. Throttle position.	Engine warm. Starting torque, lb.-ft. 1	2	3	Average.
Open...........	108.5	122.5	113.7	114.9	Open.............	87.5	92.8	92.8	91.0
Closed..........	103.3	103.3	89.3	98.6	Closed............	105.0	115.5	105.0	108.5

WATER PUMP CAPACITY RUN THROUGH ENGINE.

Engine, r. p. m.	Water temp. tank ° F.	Gross lb. (tank+water).	Weight. Can, lb. (tank).	Weight. Net, lb. (water).	Flow, in sec.	Gal. per min.[1] Actual.	Gal. per min.[1] Average.	Venturi reading, in. hg.	Gallons per min.[2] Actual.	Gallons per min.[2] Average.
1,250	73	158.0	43.0	115.0	30	27.64	27.32	1.60	27.95	28.38
1,250	74	155.0	42.5	112.5	30	27.00		1.70	28.82	
1,450	76	171.5	43.0	128.5	30	30.85	30.98	2.15	32.37	32.58
1,450	79	172.5	43.0	129.5	30	31.10		2.20	32.80	
1,650	69	183.5	43.0	140.5	30	33.74	34.58	2.70	36.34	36.65
1,650	70	190.5	43.0	147.5	30	35.42		2.80	36.97	
1,850	75	217.0	42.5	174.5	30	41.90	40.04	3.50	41.32	40.41
1,850	73	202.0	43.0	159.0	30	38.18		3.20	39.50	
2,050	78	214.5	42.5	172.0	30	41.30	43.22	3.80	43.05	42.78
2,050	82	230.5	42.5	188.0	30	45.13		3.70	42.50	

[1] By weight. [2] By venturi.

Barometer, 29.17 in. hg.

WATER PUMP CAPACITY RUN—FREE INTAKE AND DISCHARGE.

Speed, r. p. m. Pump.	Speed, r. p. m. Engine.	Drive torque,[1] lb.-ft.	Drive horsepower	Flow. Sec. for 200 lbs.	Flow. Gallons per minute.
1,875	1,250	1.45	0.518	29.0	49.7
2,175	1,450	1.60	.662	26.2	55.0
2,475	1,650	1.70	.801	22.6	63.8
2,775	1,850	1.85	.978	20.6	70.0
3,075	2,050	2.10	1.230	19.0	75.9

[1] 12-inch arm.

NOTE.—Maximum pressure at normal engine speed of 1,750 revolutions per minute is 12 pounds per square inch.

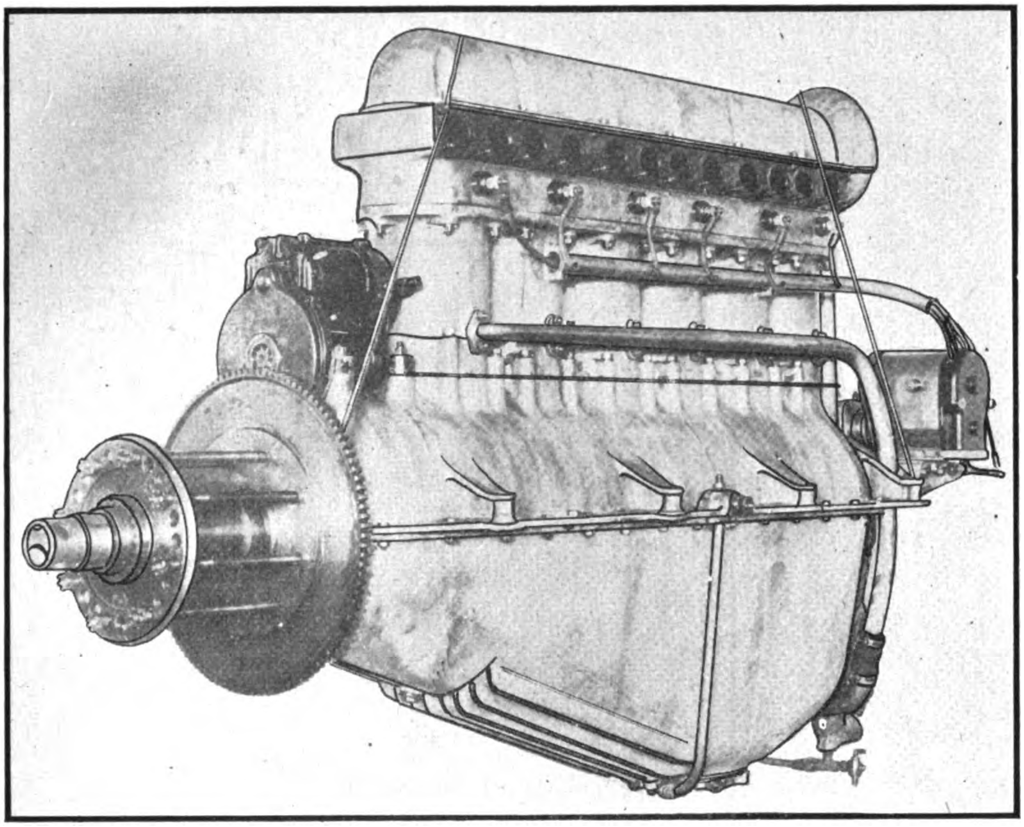


FIG. 1.—Three-quarter front view (left side).

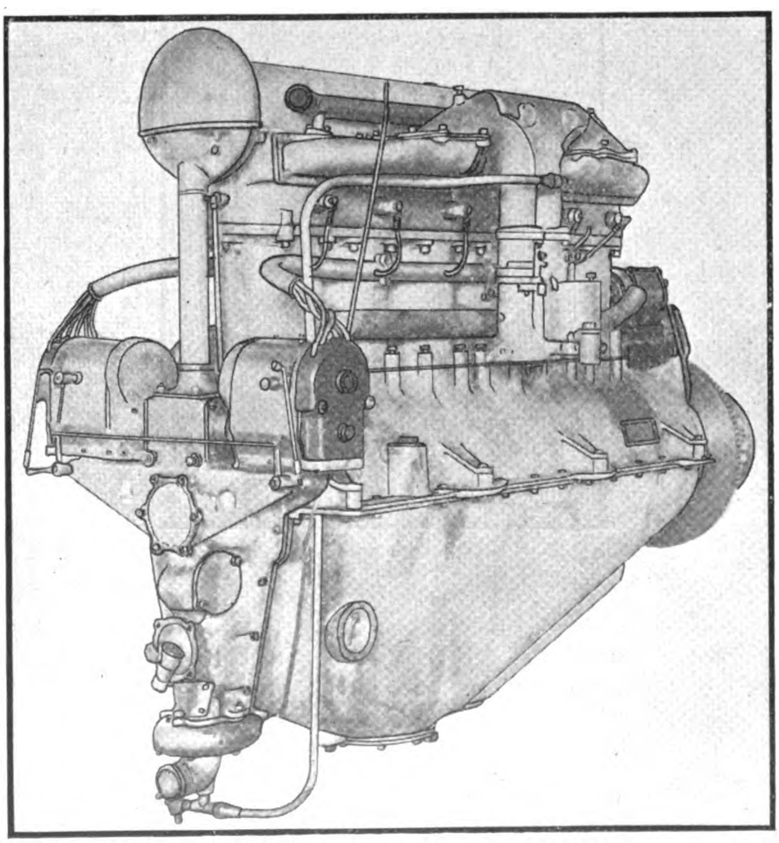


FIG. 2.—Three-quarter rear view (right side).

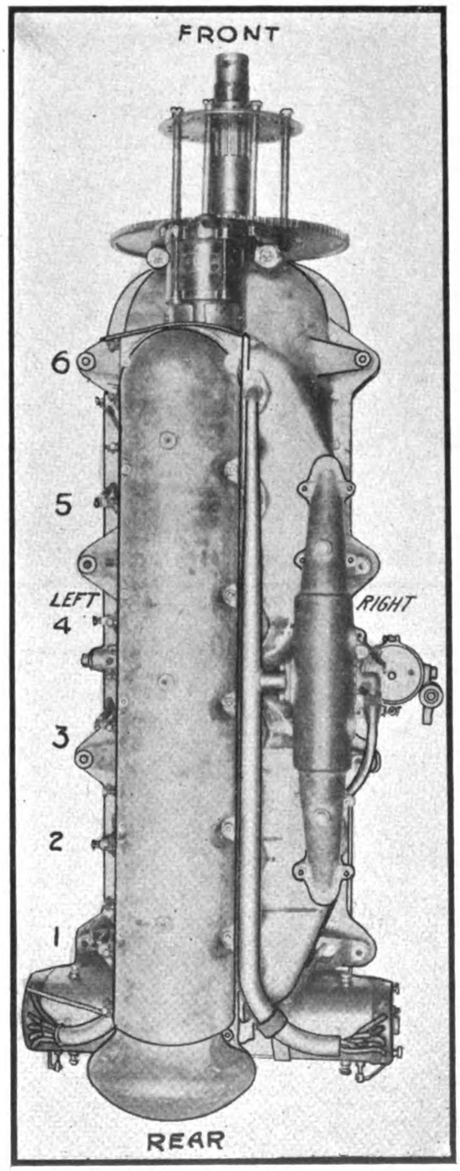


FIG. 3.—Top view.

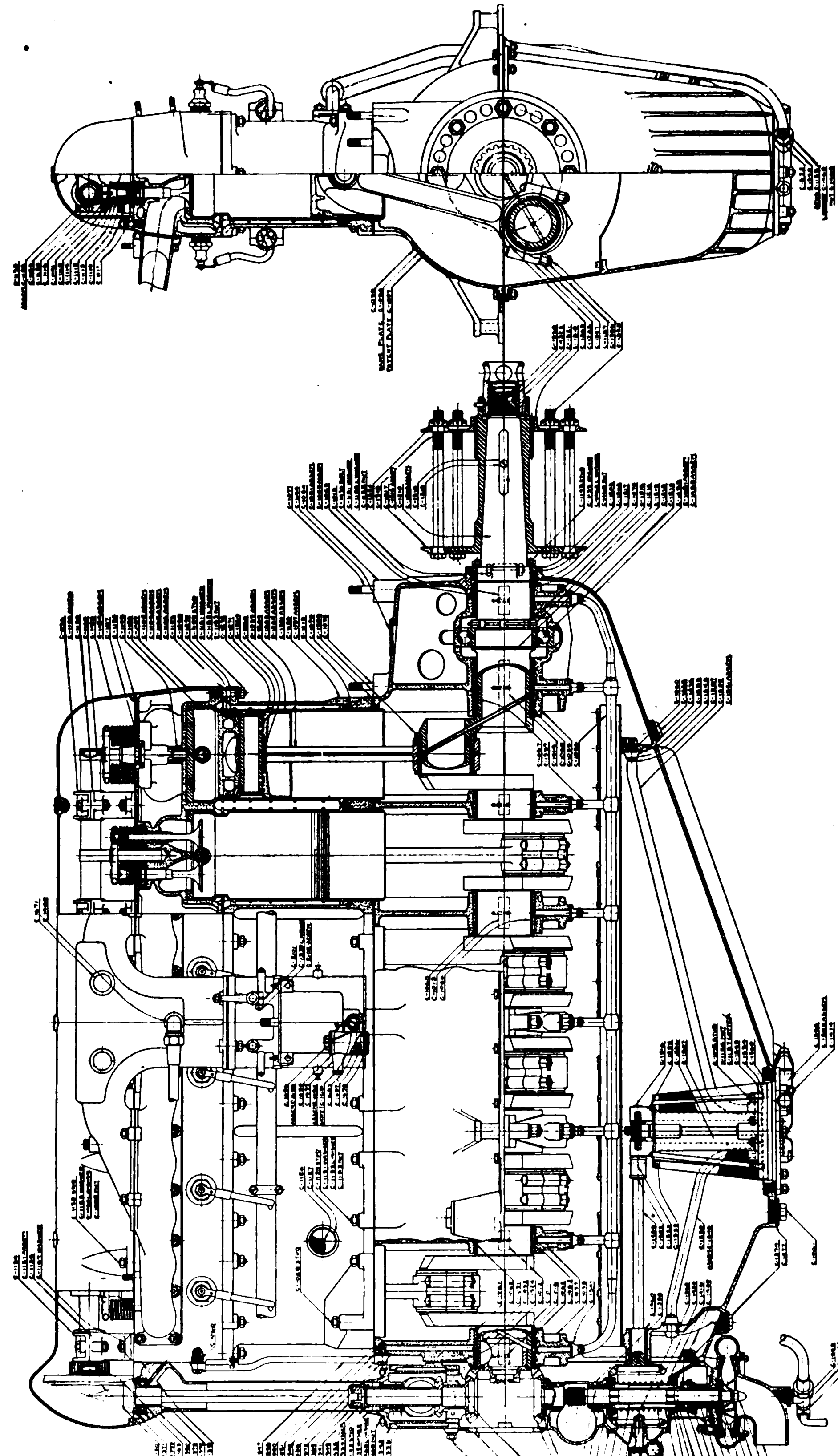


FIG. 4.—Propeller end view and longitudinal section.

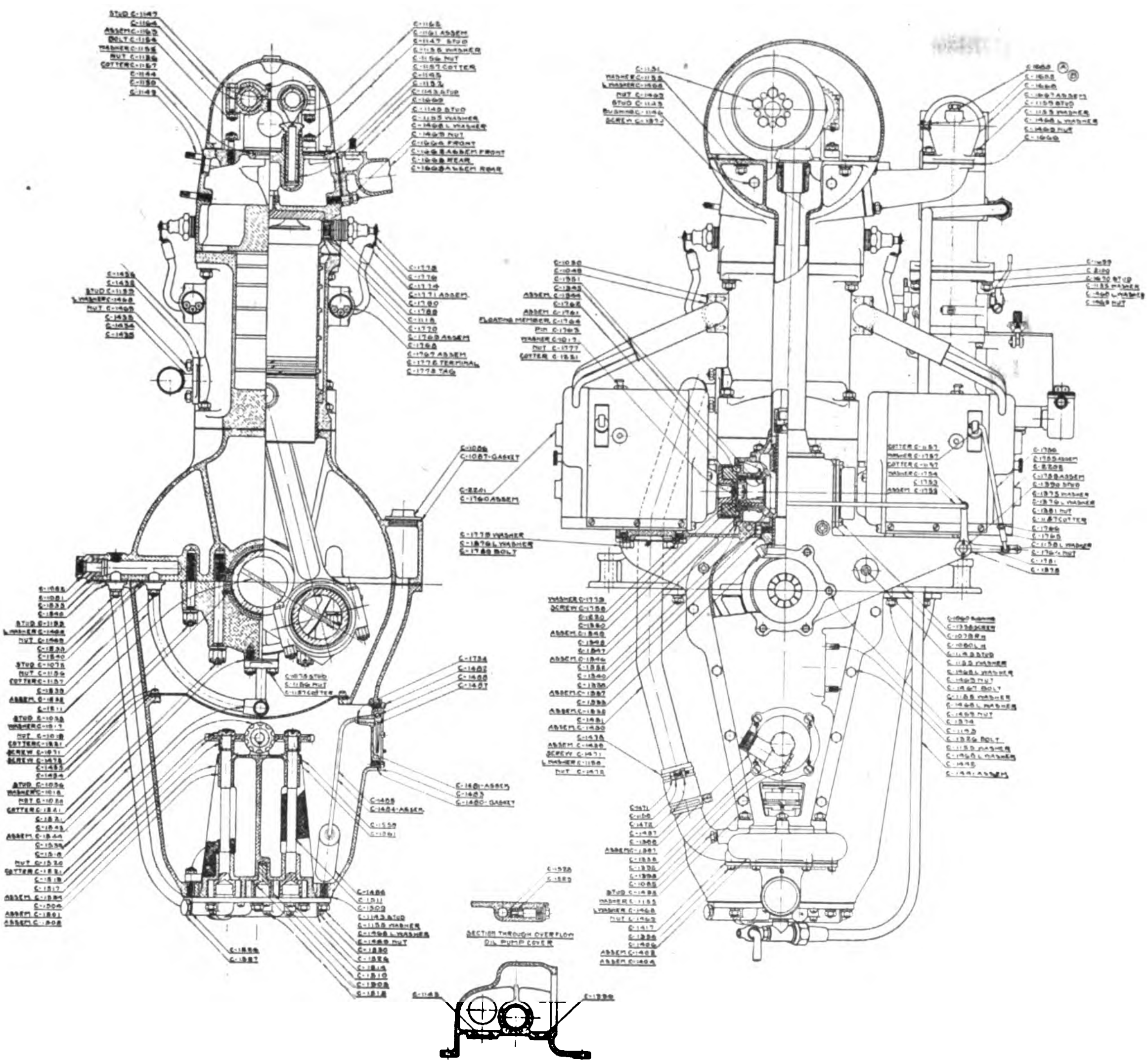


FIG. 5.—Gear end view and transverse section.

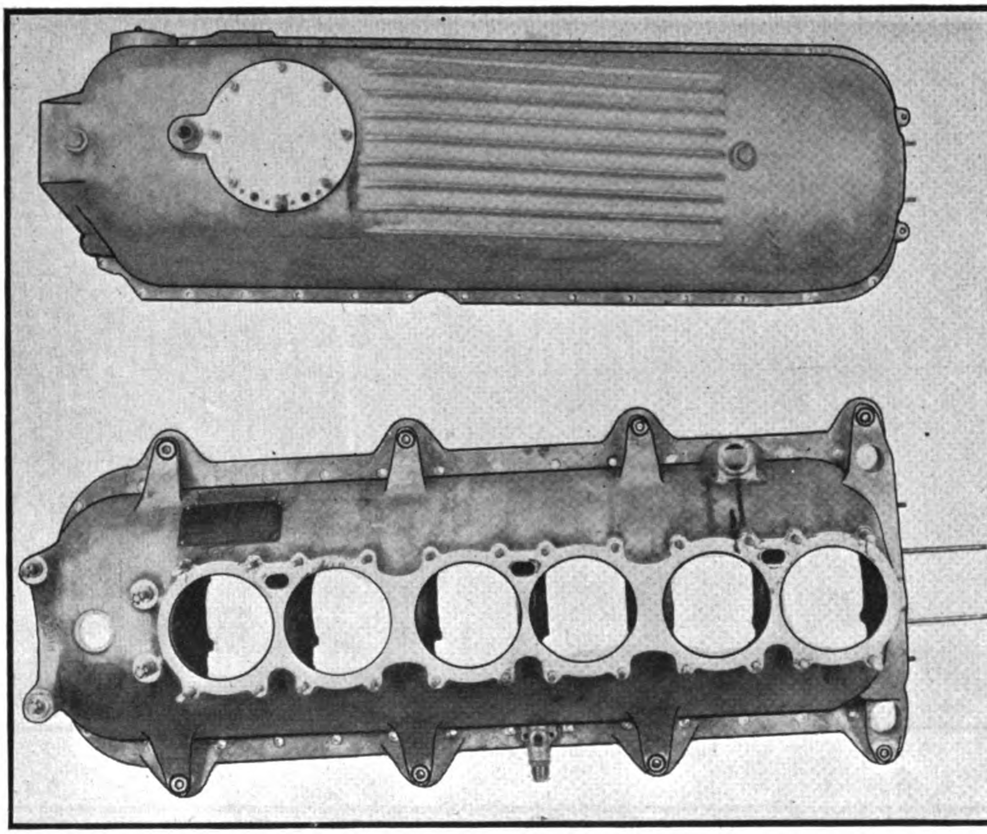


FIG. 6.—Crankcase, upper and lower halves, outside views.

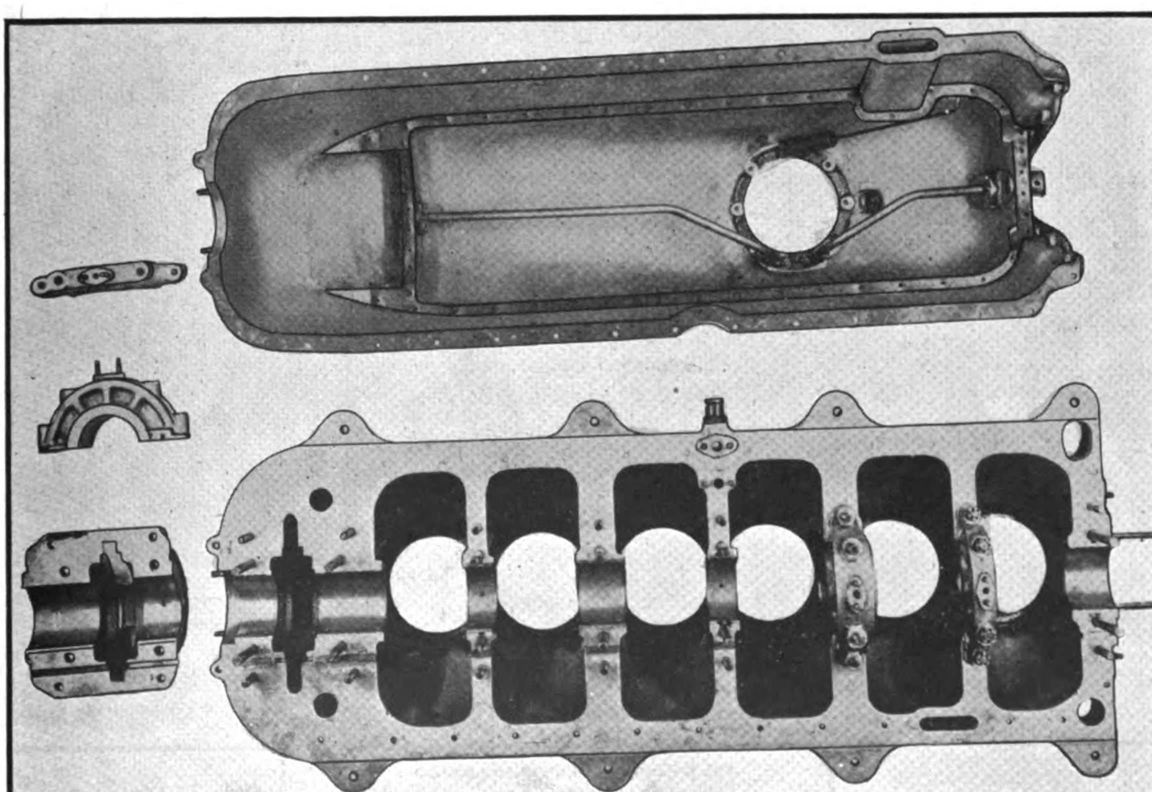


FIG. 7.—Crankcase, upper and lower halves, inside views.

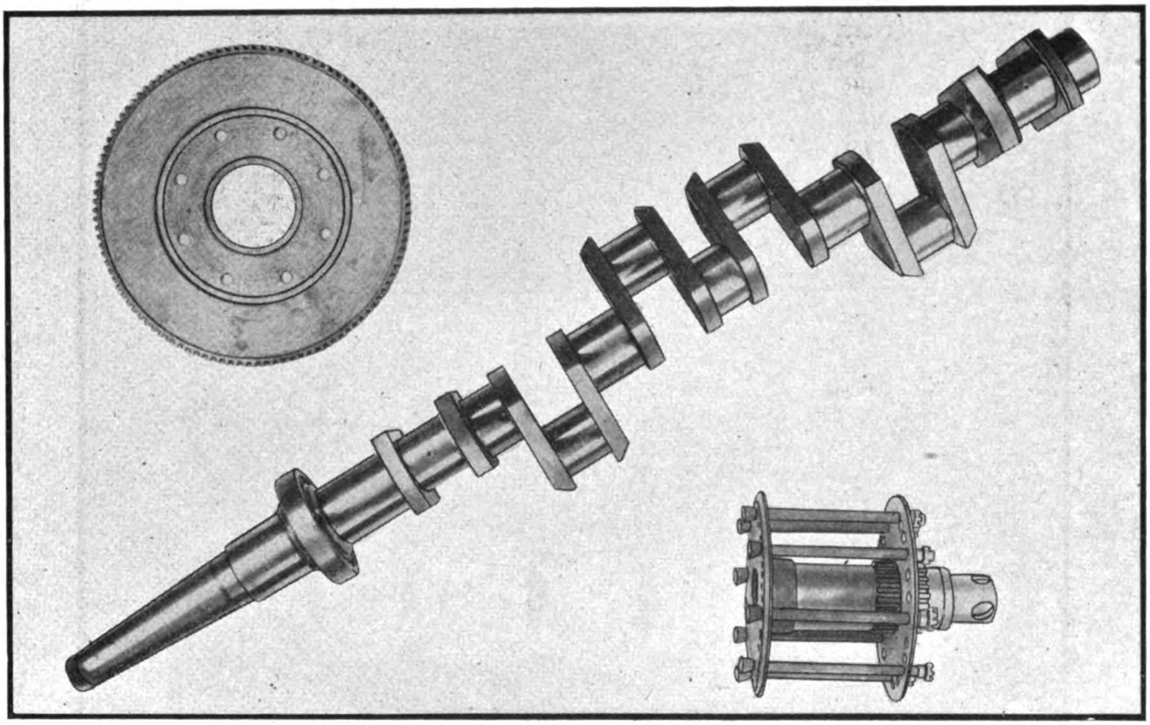


FIG. 8.—Crankshaft, propeller hub, and starting gear.

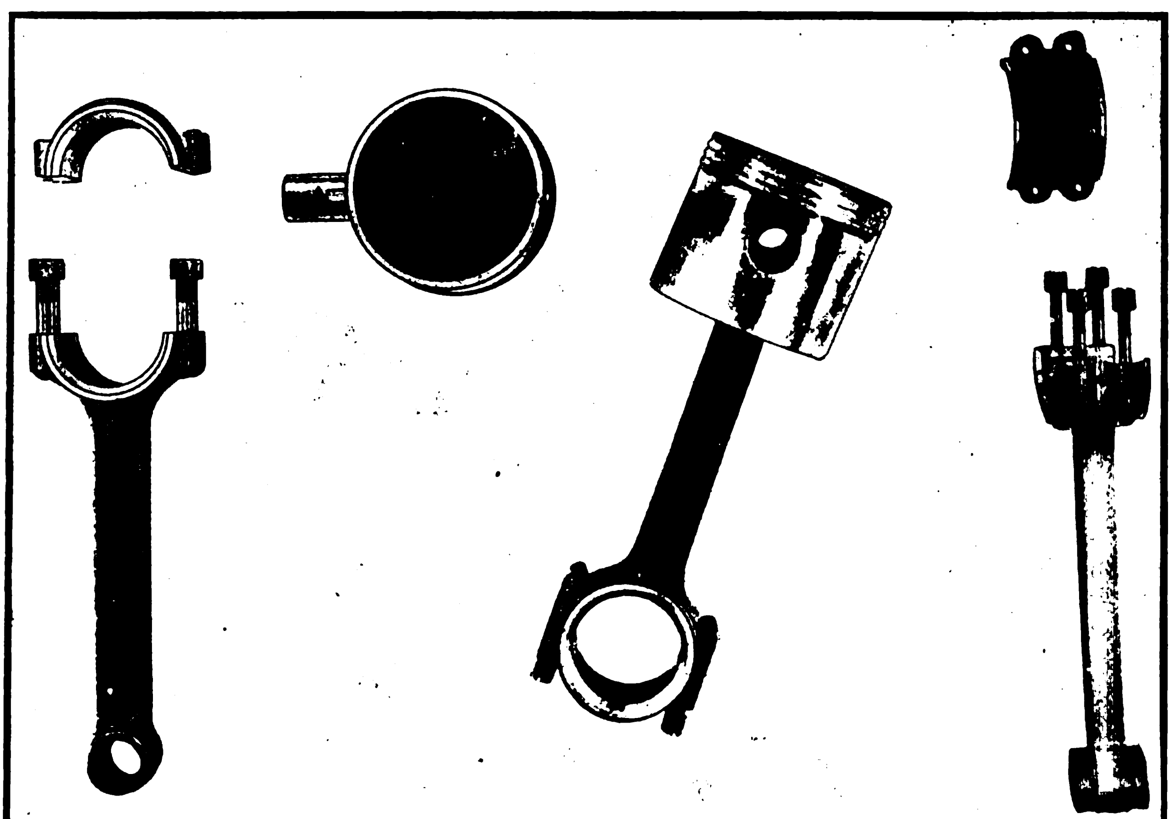


FIG. 9.—Pistons and connecting rods.

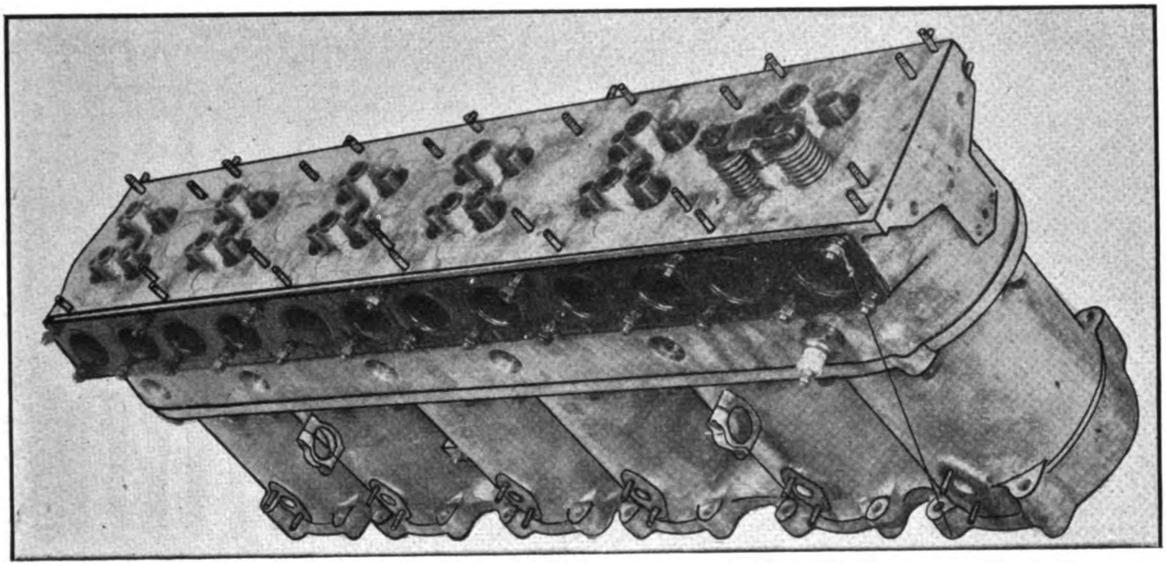


FIG. 10.—Cylinder block assembly.

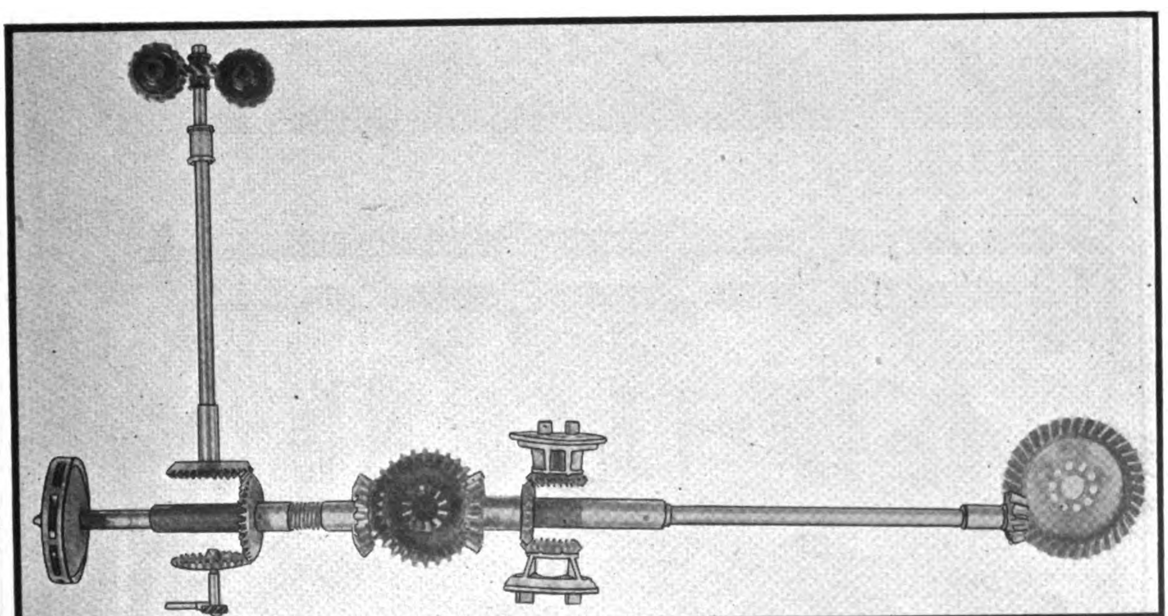


FIG. 11.—Drives laid out according to location in engine.

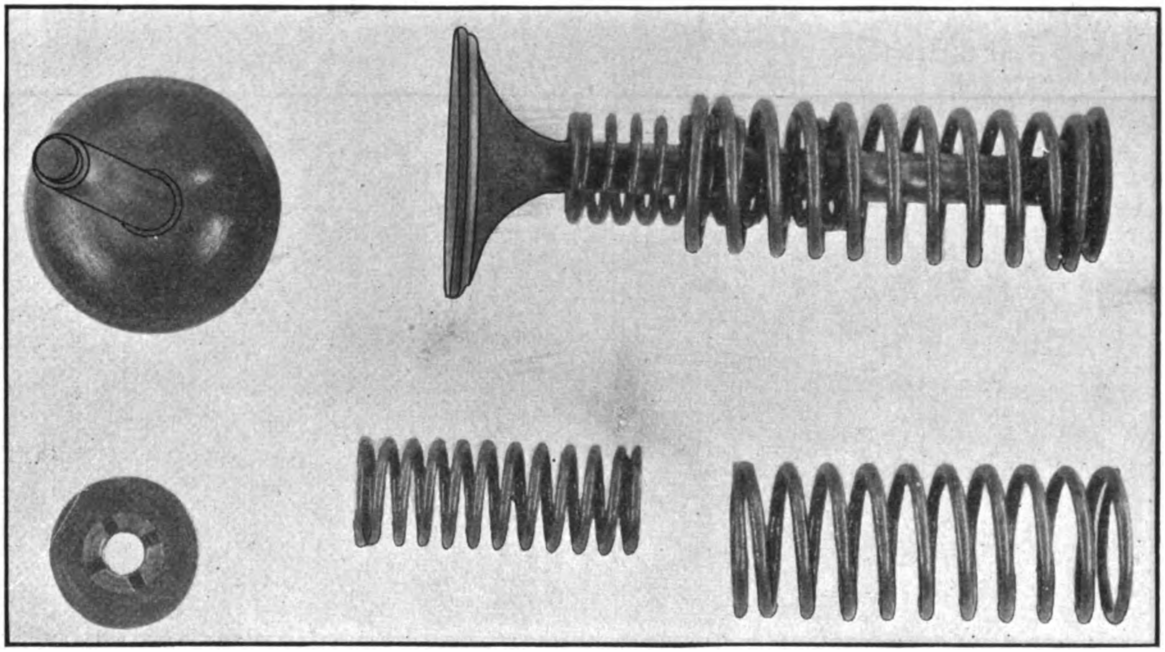


FIG. 12.—Valves and valve springs.

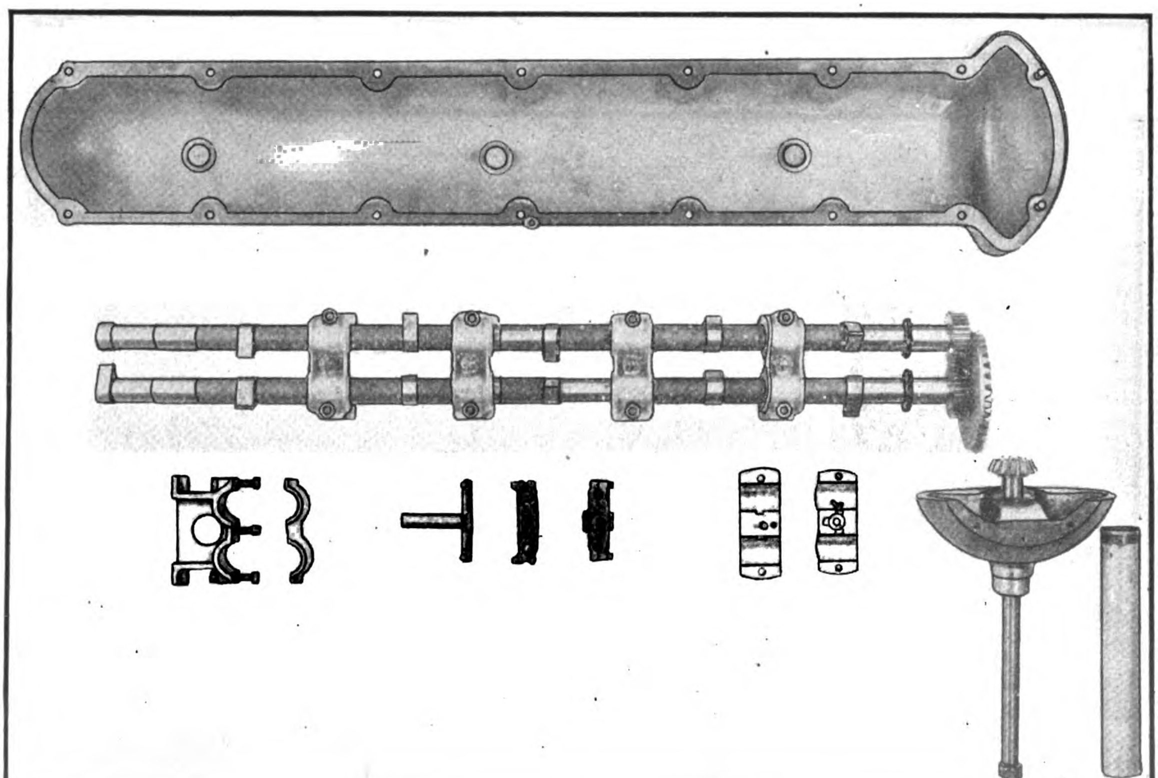


FIG. 13.—Camshafts and housing.

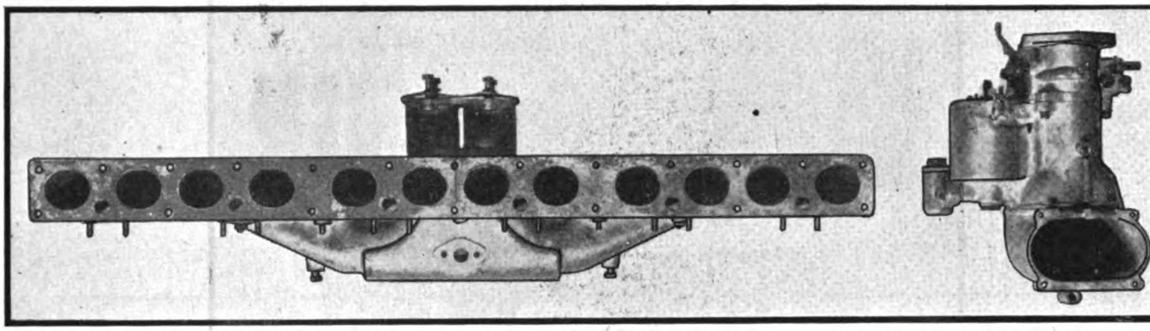


FIG. 14.—Carbureter and intake header.

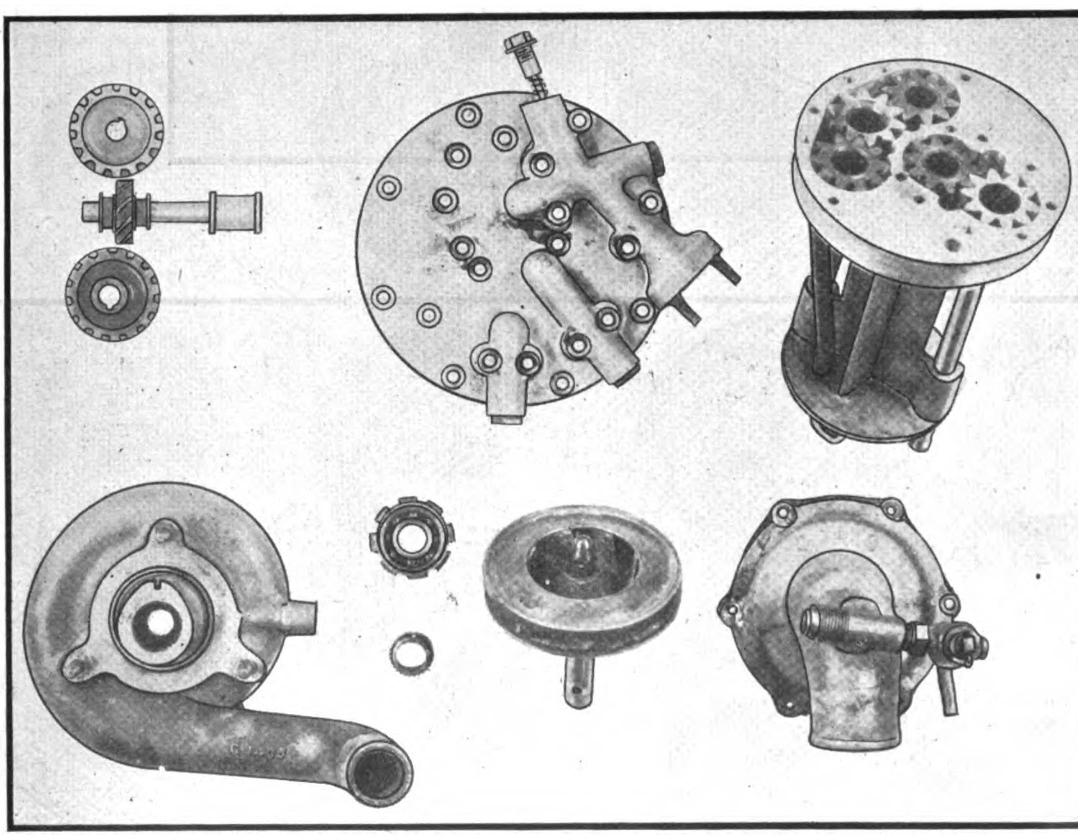


FIG. 15.—Water pump and oil pumps.

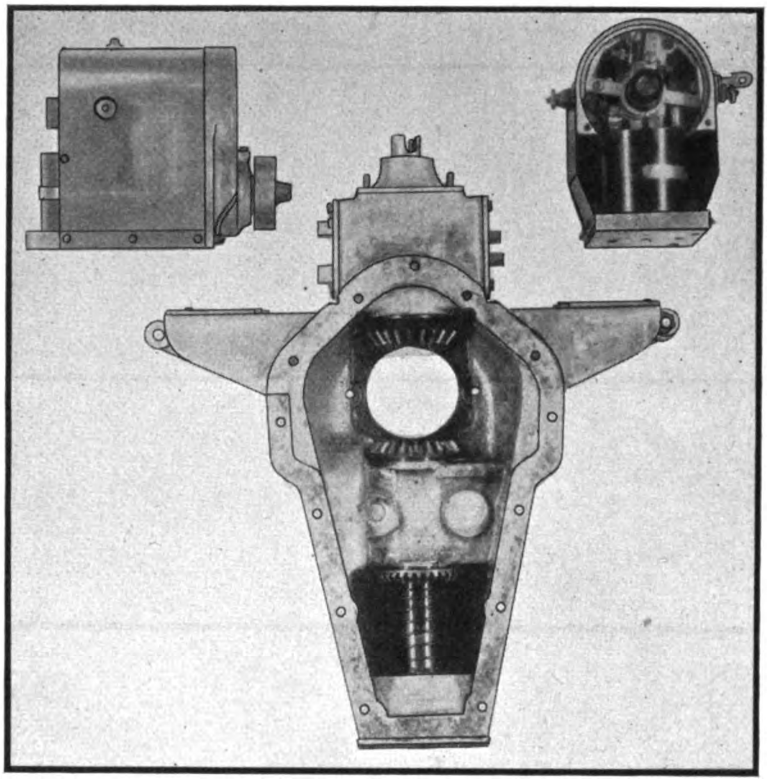


FIG. 16.—Gear case and magnetos.

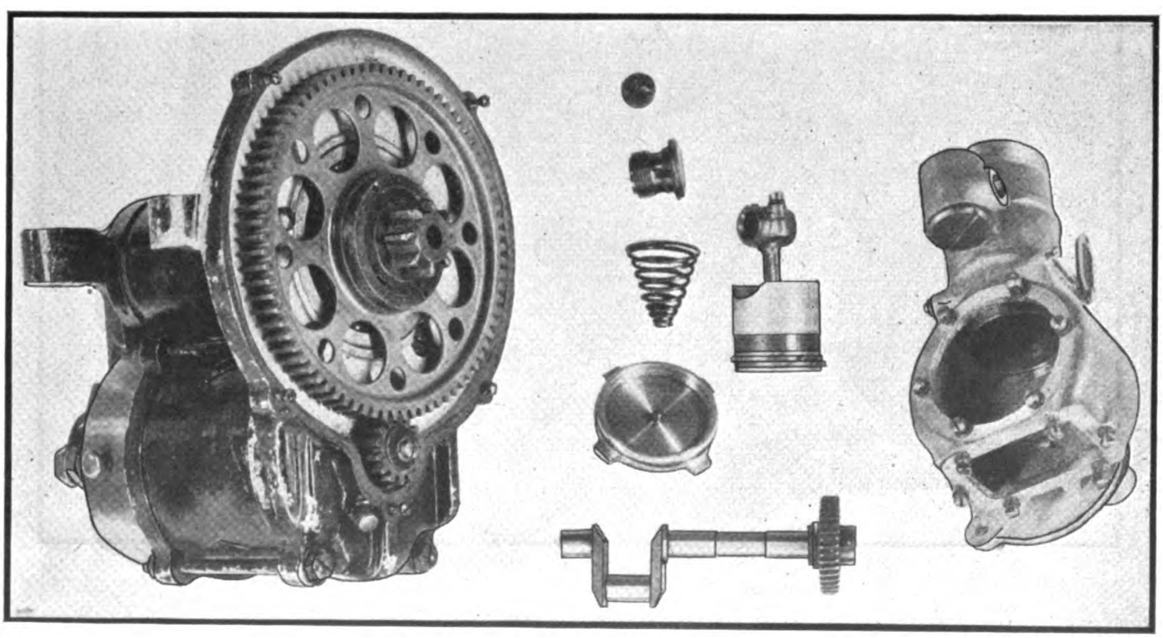


FIG. 17.—Starter and air pump.

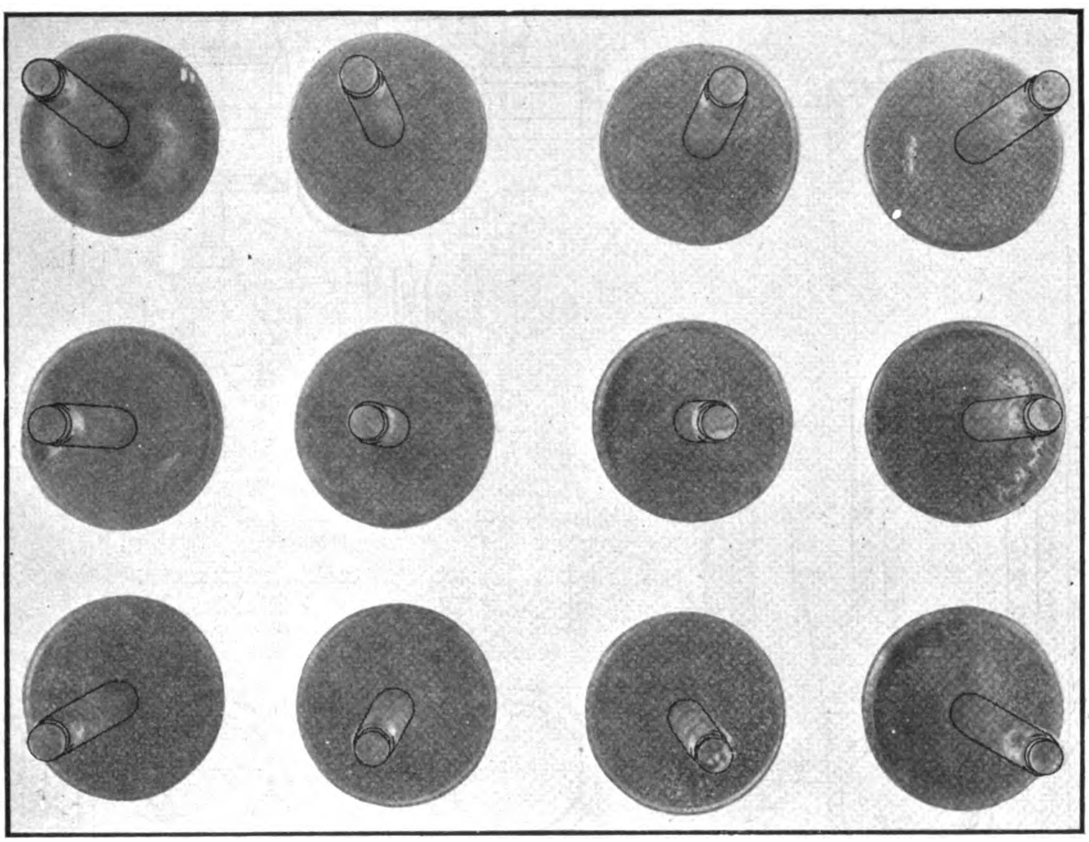
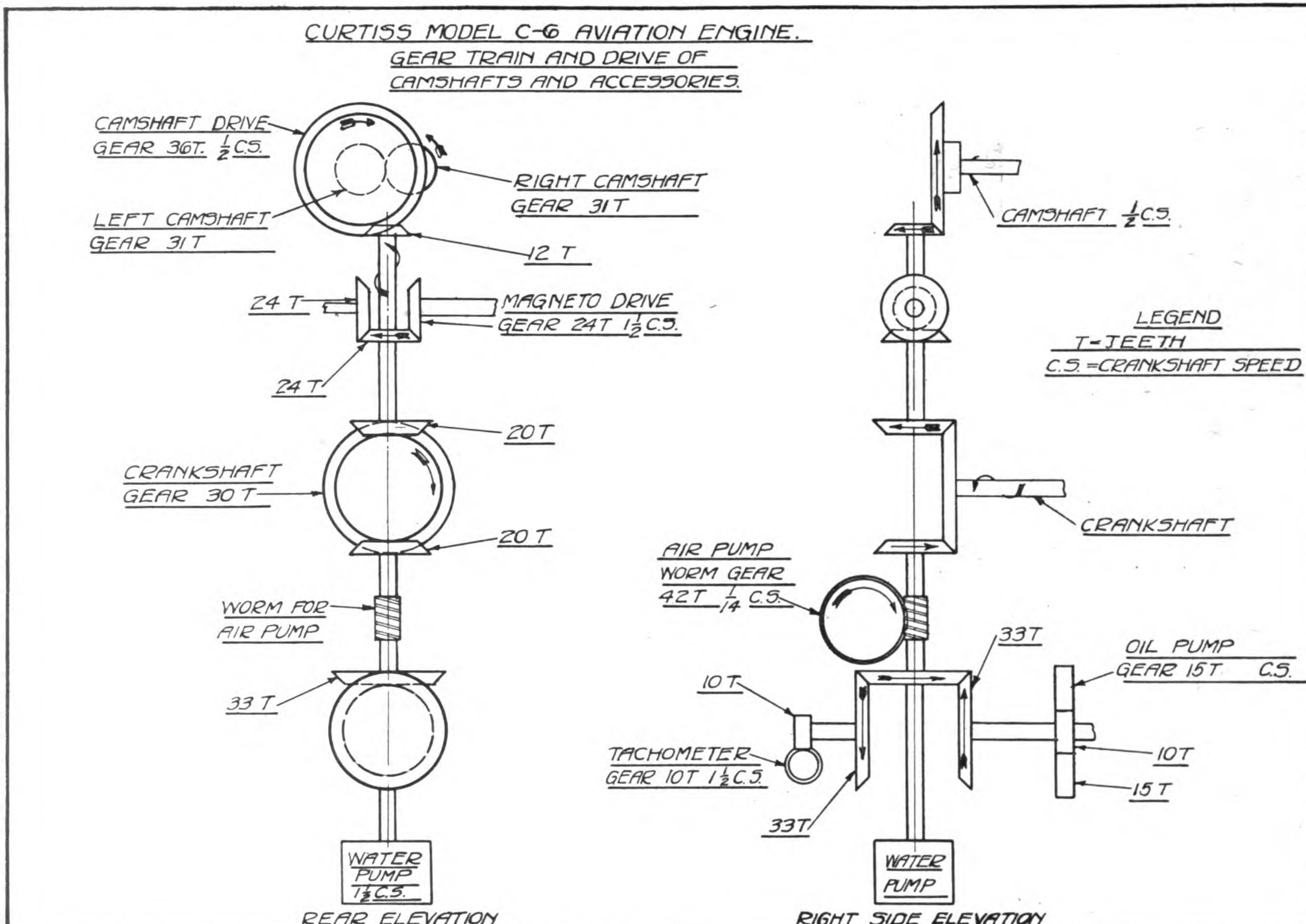


FIG. 18.—Intake valves after test.



CURTISS MODEL C-6 AVIATION ENGINE.
GEAR TRAIN AND DRIVE OF
CAMSHAFTS AND ACCESSORIES.
CAMSHAFT DRIVE
GEAR 36T. 1/2 C.S.
RIGHT CAMSHAFT
GEAR 31 T
LEFT CAMSHAFT
GEAR 31 T
12 T
24 T
MAGNETO DRIVE
GEAR 24T 1 1/2 C.S.
24 T
20 T
CRANKSHAFT
GEAR 30 T
20 T
WORM FOR
AIR PUMP
33 T
WATER
PUMP
1 1/2 C.S.
REAR ELEVATION
CAMSHAFT 1/2 C.S.
LEGEND
T-TEETH
C.S.=CRANKSHAFT SPEED
CRANKSHAFT
AIR PUMP
WORM GEAR
42T 1/14 C.S.
33T
OIL PUMP
GEAR 15T C.S.
10 T
TACHOMETER
GEAR 10T 1 1/2 C.S.
10T
15 T
33T
WATER
PUMP
RIGHT SIDE ELEVATION

FIG. 19.

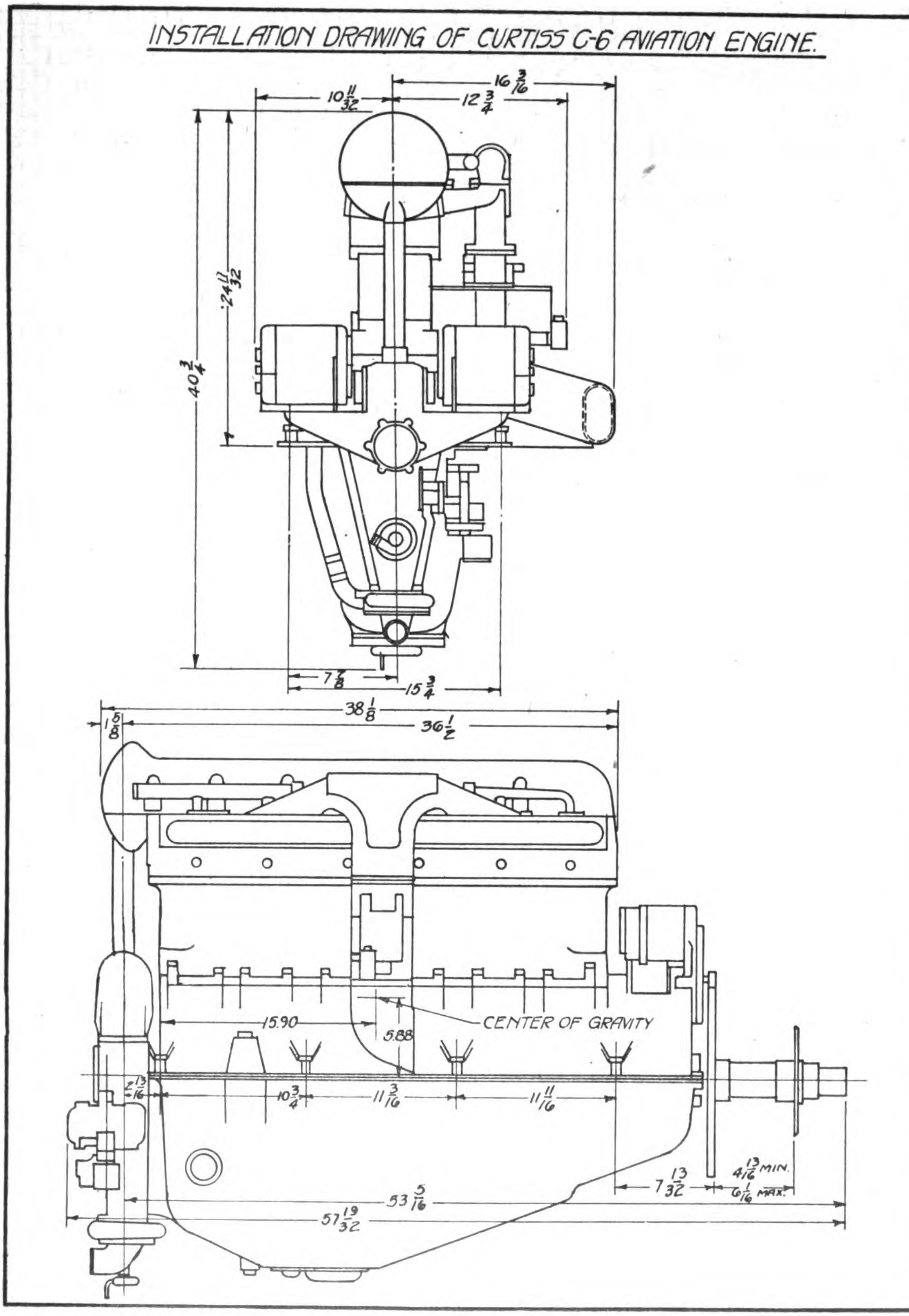

INSTALLATION DRAWING OF CURTISS C-6 AVIATION ENGINE.
CENTER OF GRAVITY
15.90
5.88
MIN.
MAX.

FIG. 20.

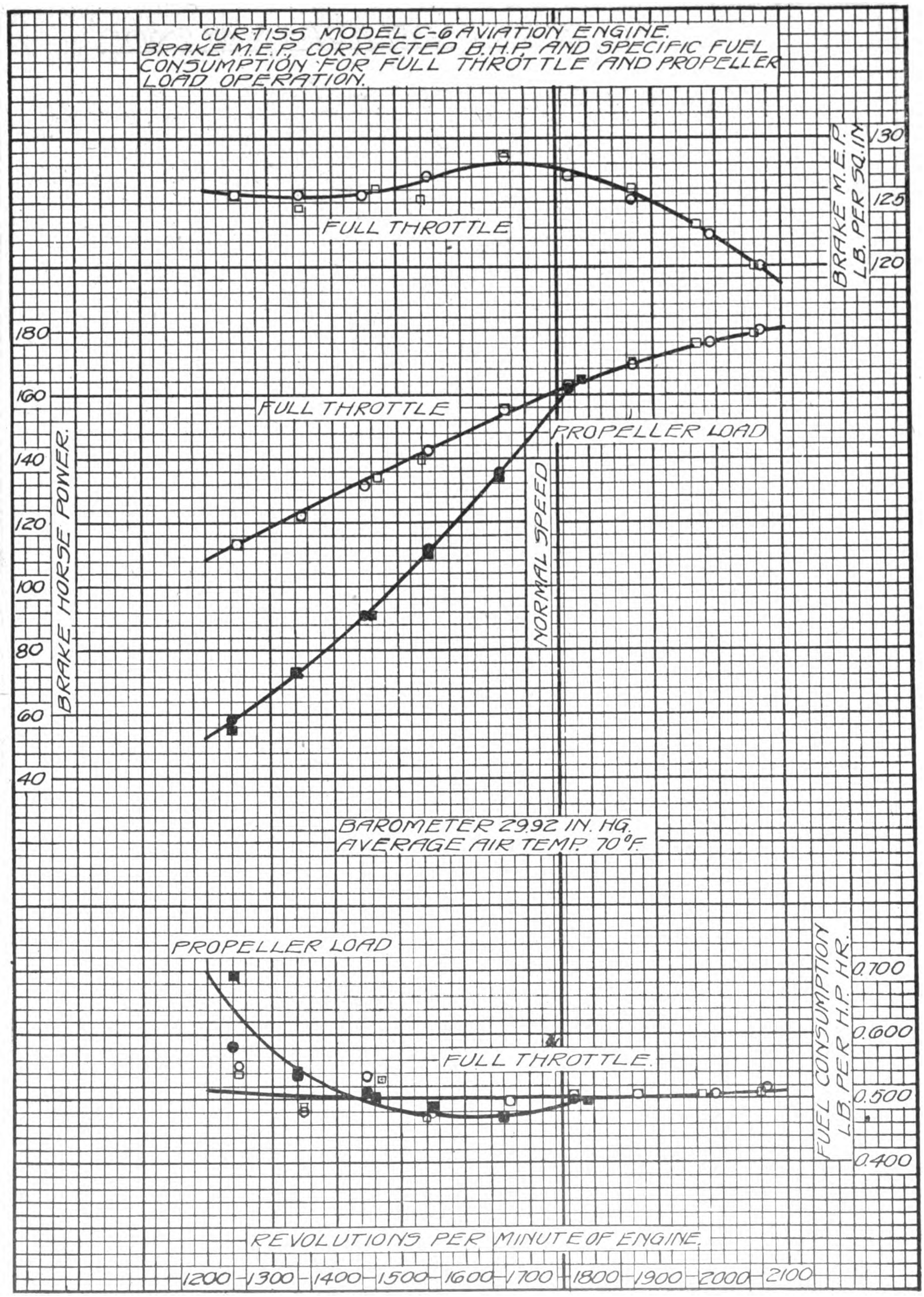

CURTISS MODEL C-6 AVIATION ENGINE.
BRAKE M.E.P. CORRECTED B.H.P. AND SPECIFIC FUEL CONSUMPTION FOR FULL THROTTLE AND PROPELLER LOAD OPERATION.
BRAKE M.E.P. LB. PER SQ. IN.
130
125
120
FULL THROTTLE
180
160
140
120
100
80
60
40
BRAKE HORSE POWER.
FULL THROTTLE
PROPELLER LOAD
NORMAL SPEED
BAROMETER 29.92 IN. HG.
AVERAGE AIR TEMP. 70°F.
PROPELLER LOAD
FULL THROTTLE.
FUEL CONSUMPTION LB. PER H.P. HR.
0.700
0.600
0.500
0.400
REVOLUTIONS PER MINUTE OF ENGINE.
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100

FIG. 21.

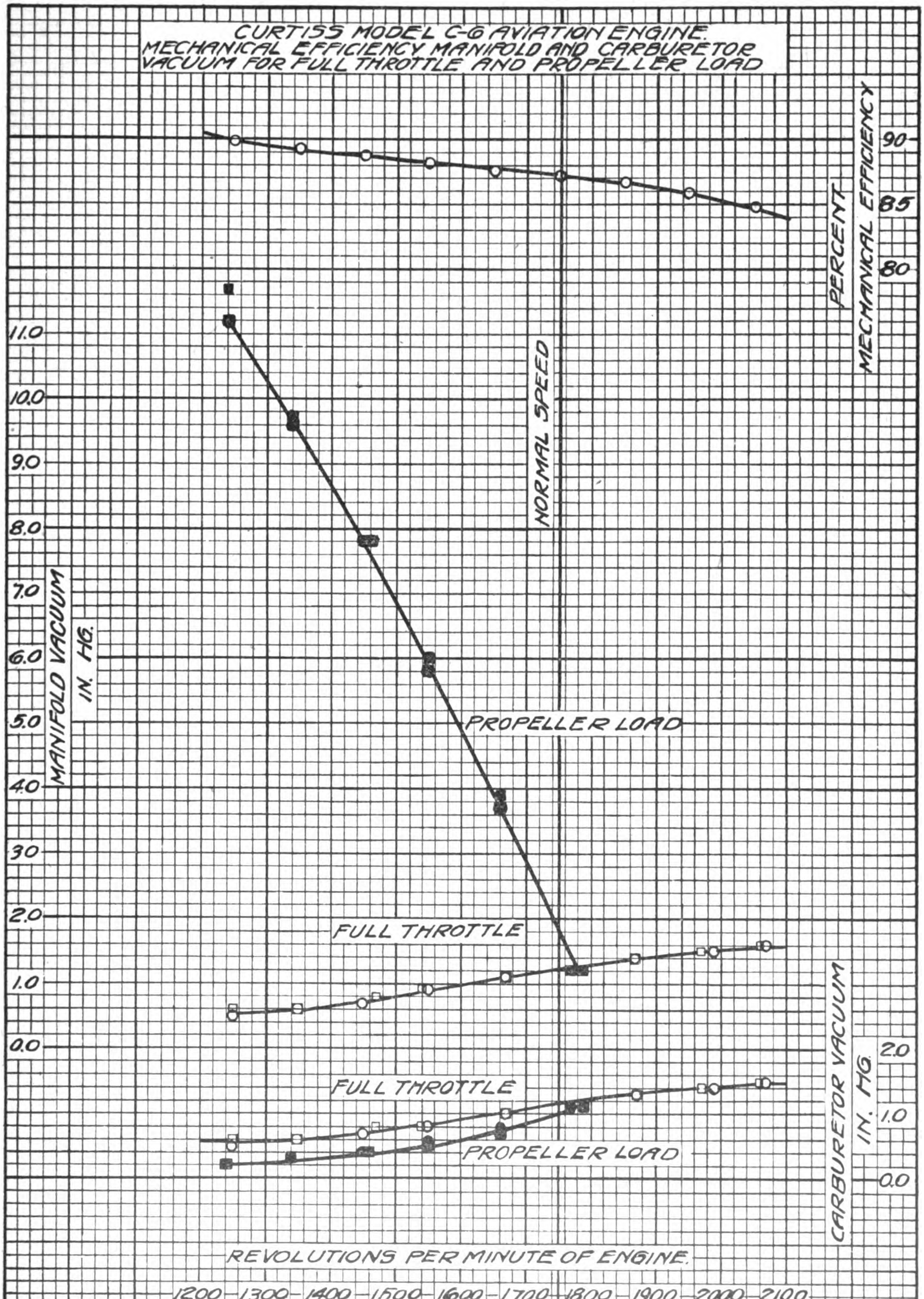

CURTISS MODEL C-6 AVIATION ENGINE.
MECHANICAL EFFICIENCY MANIFOLD AND CARBURETOR
VACUUM FOR FULL THROTTLE AND PROPELLER LOAD
PERCENT
MECHANICAL EFFICIENCY
90
85
80
NORMAL SPEED
MANIFOLD VACUUM
IN. HG.
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
PROPELLER LOAD
FULL THROTTLE
FULL THROTTLE
PROPELLER LOAD
CARBURETOR VACUUM
IN. HG.
2.0
1.0
0.0
REVOLUTIONS PER MINUTE OF ENGINE.
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100

FIG. 22.

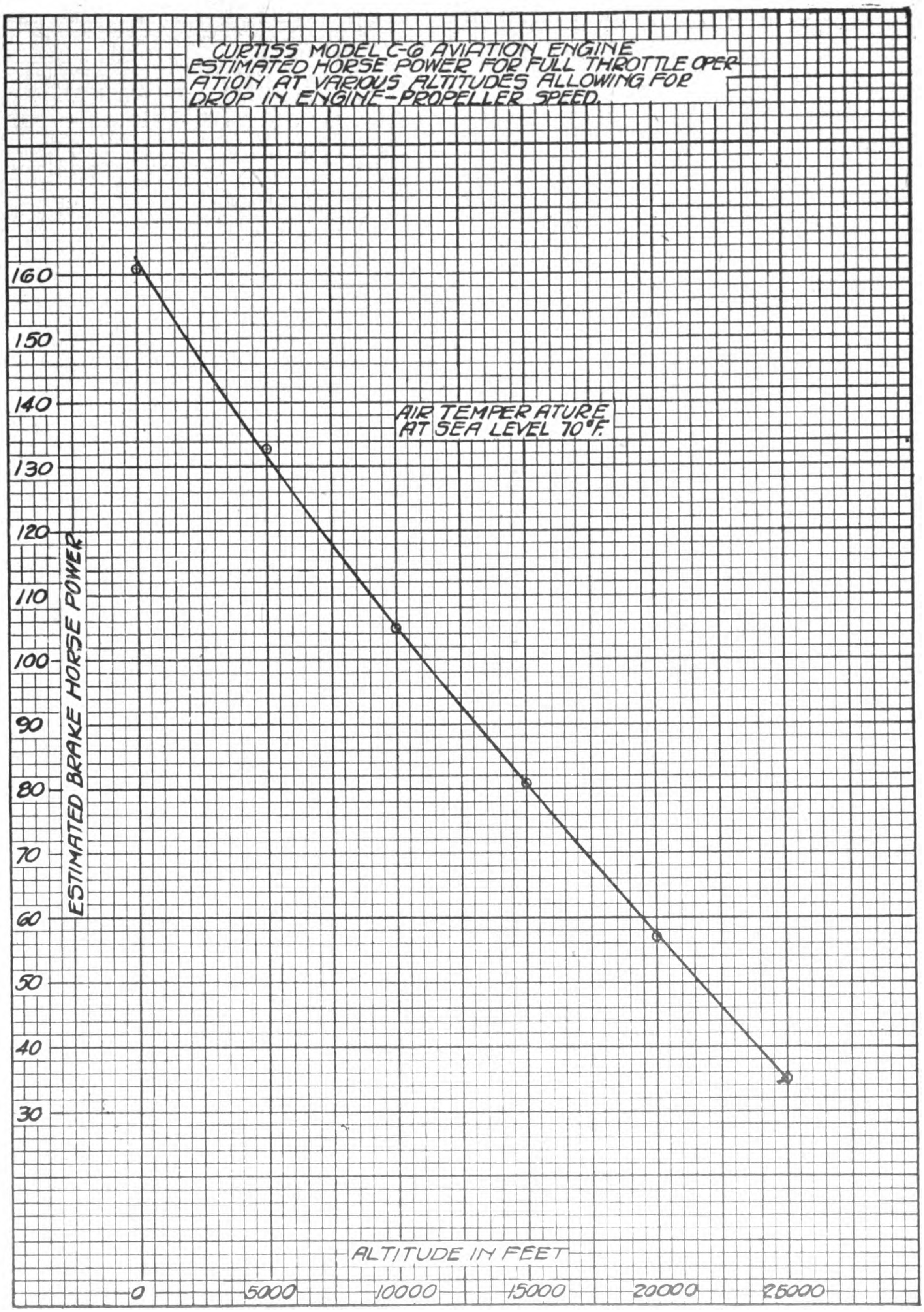

CURTISS MODEL C-6 AVIATION ENGINE
ESTIMATED HORSE POWER FOR FULL THROTTLE OPERATION AT VARIOUS ALTITUDES ALLOWING FOR DROP IN ENGINE-PROPELLER SPEED.
AIR TEMPERATURE AT SEA LEVEL 70°F.
ESTIMATED BRAKE HORSE POWER
160
150
140
130
120
110
100
90
80
70
60
50
40
30
ALTITUDE IN FEET
0
5000
10000
15000
20000
25000

FIG. 23.

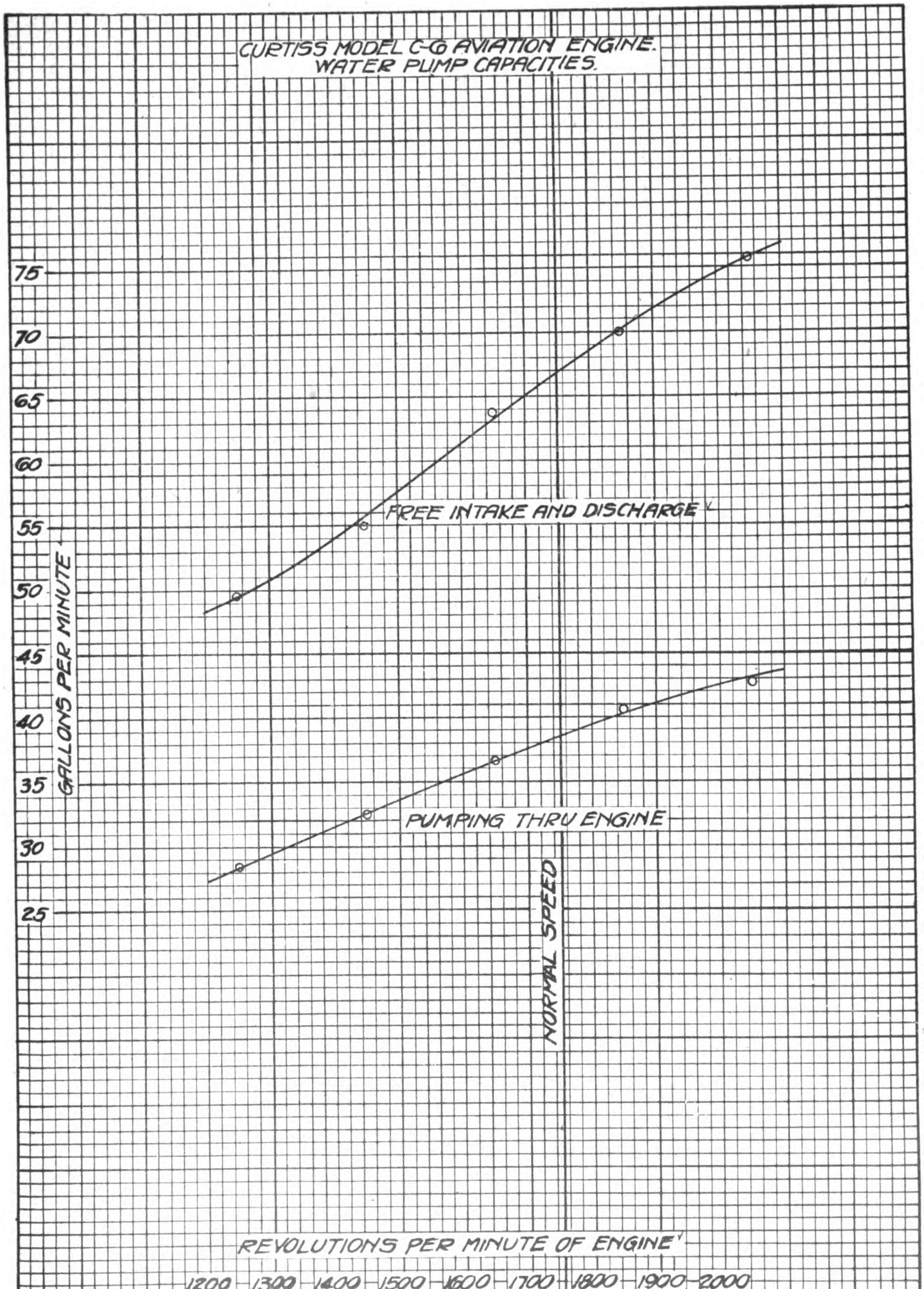

CURTISS MODEL C-6 AVIATION ENGINE.
WATER PUMP CAPACITIES.
75
70
65
60
55
50
45
40
35
30
25
GALLONS PER MINUTE
FREE INTAKE AND DISCHARGE
PUMPING THRU ENGINE
NORMAL SPEED
REVOLUTIONS PER MINUTE OF ENGINE
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIG. 24.

[redacted] ONLY
File D 52.41 / Curtiss / 24 *McCOOK FIELD REPORT, SERIAL No. 1780*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV March 15, 1922 No. 330

STANDARD ENGINE REPORT ON CURTISS 12-CYLINDER MODEL C-12, GEARED AVIATION ENGINE, RATED AT 400 H. P. AT 2250 REVOLUTIONS PER MINUTE (ENGINE SPEED)

(POWER PLANT SECTION REPORT)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
November 25, 1921

7

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INDEX.

STANDARD ENGINE REPORT ON CURTISS 12-CYLINDER, MODEL C-12, GEARED AVIATION ENGINE, RATED AT 400 H. P. AT 2,250 REVOLUTIONS PER MINUTE (ENGINE SPEED).

OBJECT OF TEST.

The object of this test was to obtain complete information concerning the design and the performance of the Curtiss 12-cylinder, model C-12, geared aviation engine, rated at 400 horsepower at 2,250 revolutions per minute (engine speed).

SUMMARY OF TEST RESULTS.

Brake horsepower at full throttle, normal speed, 427.4 brake horsepower at 2,250 revolutions per minute (engine speed).

Fuel consumption at normal speed, 0.503 pound per (actual) brake horsepower-hour.

Oil consumption at normal speed, 0.0832 pound per (actual) brake horsepower-hour.

Brake mean effective pressure at normal speed, 131.3 pounds per square inch.

Total weight, dry, 698.0 pounds.

Weight, dry, per normal brake horsepower, 1.633 pounds.

CONCLUSIONS.

The engine on test showed excellent power, developing a higher output per unit of weight than any water-cooled engine heretofore tested by the Engineering Division. The fuel economy is good, but the oil consumption is excessive. A number of features of the design would have to be changed to make the engine suitable for service use.

No definite conclusions are possible as to the reliability of this engine until it has been subjected to a 50-hour test.

DESCRIPTION.

NOTE.—This engine is a redesigned Curtiss Kirkham 12-cylinder engine, which is completely described in Engineering Division report, Serial No. 811. The principal differences are as follows:

Curtiss C-12.	Curtiss Kirkham 12-cylinder.
Detachable en-bloc water jackets...	Cylinder water jackets cast in pairs, integral with upper half of crank case.
Eight crank-shaft bearings (3 inches diameter).	Five crank-shaft bearings (2.5 inches diameter).
One spark plug on each side of cylinder.	Both sparks plugs on intake side of cylinder.
Claudel-Hobson inverted carburetors.	Ball & Ball carburetors in the Vee.
Berkshire magnetos...............	Berling magentos.

TYPE.

Name.. Curtiss.
Model.. C-12.
Serial number of engine tested:
  Manufacturer's.................................... No. 4.
  A. S.. No. 94975.

Number of cylinders.................................. 12.
Arrangement.. 60° Vee.
Drive.. Geared.
Cooling.. Water.
Cycle.. Four.
Fuel... Gasoline.
Tractor pusher...................................... Either.
Adapted to cannon.................................. No.

MANUFACTURER.

Curtiss Aeroplane & Motor Corporation, Garden City, Long Island.

CHARACTERISTIC FEATURES.

Steel cylinder liners with integral combustion chambers, screwed into aluminum head casting; detachable en-bloc aluminum water jackets permitting cooling water in direct contact with sides of cylinder barrel; four separate cam shafts; four directly actuated valves per cylinder; herringbone reduction gears; wet sump; articulated connecting rods; two Claudel-Hobson inverted carburetors and two Berkshire magnetos with provision for battery excitation in fully retarded position.

Crankcase (see figs. 6 and 7):
  Material........................... Aluminum alloy.
  Parted.............................. In horizontal plane passing through centerline of crank shaft.
  Clamped together................. With small bolts and nuts along parting flange.
  Number of crankshaft bearings..... Eight.
  Type of bearings.................. Plain.
    Material........................ Bronze shell lined with white metal.
  Bearings are carried............... In transverse webs in upper half of crankcase and in bearing caps.
  Bearings are secured.............. With four countersunk brass screws for each half of bearing.
  Adjustment of bearings............ None..
  Oil grooves in bearings............ None.
  Accessory gear drive housing....... Bolted to rear of crankcase.
  Engine mounting lugs or flanges—
    Number......................... Ten.
    Location........................ Five on each side of upper case.
    Type............................ Case is buttressed to form lug.
    Number of bolts in each lug.... One.
  Upper half—
    Type of webs.................. Single.
    Bearing caps—
      Type........................ I beam section.
      Material.................... Aluminum alloy.
      Retained.................... By four studs and nuts. Also have positioning key between studs on the right side.
  Breathers:
    Number........................ Six.
    Location....................... Inside of Vee at webs Nos. 2, 4, 6.
    Construction.................... Cored passages in crankcase.

Crankcase—Continued.

- Oil passages—
  - From mounting flange through No. 4 web to inside of case supplying oil to main bearings.
  - From around No. 1 bearing to upper vertical shaft bearing and directly up to the top of crankcase supplying oil for camshafts.
  - From No. 8 bearing by oil tube to front propeller shaft bearing.
- Lower half—
  - Function: Oil sump.
  - Webs: None.
  - Breathers: None.
  - Compartments: Four.[1]
  - Oil passages: From sump at each end by oil tube to scavenging pump.

NOTE.—Oil pump is attached in the bottom of the crankcase. There are three oil drain plugs. An oil gage with cork float is on the right side. There are nine cooling fins on the underside in the slipstream from the propeller. The oil pump drive shaft is carried in a bronze bearing at the rear. There is an oil drip pan dividing the main body of the crankcase into two compartments. The oil filler passageway by-passes the drip pan to the oil sump.

Crankshaft (see figure 8):

- Type: Integral.
- Material: Chrome nickel steel.
- Bored: Through journals and crank pins.
- Crankshaft gear retained: By three internal keys.
- Oil passages in shaft: By oil tubes from main bearings to crank pins.

Reduction gear (see fig. 8):

- Ratio (propeller speed to crankshaft speed): 3:5.
- Type of gearing: Herringbone.
- Gears—
  - Material: Chrome nickel steel.
  - Fastened on shaft: Bolted to integral flanges.
- Propeller shaft—
  - Material: Chrome nickel steel.
  - Front bearing: Bronze shell with white metal lining.
  - Thrust bearing—
    - Type: Single row ball bearing.
    - Adjustment endwise: By shims.
    - Retained: By threaded nut and lock wire.
    - Bored: Entire length.
- Provision to prevent leakage where shaft passes through case: By split aluminum ring threaded opposite to direction of rotation.

Propeller hub (see fig. 8):

- Material: Steel.
- Type: Rear flange integral with propeller shaft. Front flange removable over splines.

Connecting rods (see fig. 9):

- Type: Main rods and articulated rods.
- Material: Alloy steel.
- Section: I beam.
- Main rod—
  - Big end arrangement: Cap held with four bolts over crankpin.
  - Type of bearing: Plain.
  - Material of bearing: Bronze shell lined with white metal.
  - Bearings are retained in rod: By four brass dowel pins.
  - Adjustment of crankpin bearing: None.
- Small end bearing—
  - Type: Bushing.
  - Material: Bronze.
  - Retention: Pressed in.
  - Adjustment: None.
- Oil passages in rod: Oil hole in bearing shell registers with hole in crank pin Oil is distributed to hinge pin bushing by two oil tubes. The upper end has two oil holes on upper side.

[1] The four compartments are front sump, rear sump, and upper and lower halves (divided by oil pan).

Connecting rods—Continued.

- Articulated rod—
  - Lower end arrangement: Forked over hinge pin support or lug on main rod.
  - Lower end bearing—
    - Number: Two.
    - Type: Plain.
    - Material: Bronze.
    - Retention: Pressed in.
    - Adjustment: None.

The hinge pin is held from rotating in its bearing, in the main rod, by a groove in the pin which registers with the bolt holding it in place.

Pistons (see fig. 9):

- Type: Trunk.
- Material: Aluminum.
- Internal ribbing: One concentric rib and one cross rib.
- Rings—
  - Number: Three.
  - Type: One-piece peened rings with diagonal gap.
  - Material: Cast iron.
  - Location: Above piston pin.
  - Oil scrapers: One groove above piston pin communicating by six holes to inside of piston.

Piston pins (see fig. 9):

- Material: Steel.
- Bored: Taper from each end.
- Retained in piston: By two snap rings.
- Oil holes: Three.

Cylinders (see fig. 10):

- Barrel—
  - Type: Sleeve, with integral head screwed into cylinder head.
  - Material: High carbon steel.
  - Construction: Hydraulic forging, heat treated.
  - Stiffening ribs (on outside): Six (annular).
- Head—
  - Material and construction of valve seats: Bored in steel cylinder head.
  - Construction of valve ports: Cored passages in aluminum cylinder head.
  - Material of valve guides: Cast iron.
  - Construction: Removable.
  - Provision for cooling water to reach valve guides and seats: Cored passages in aluminum cylinder head.
  - Location and construction of spark plug bosses: Bronze bushings inserted inside through threaded portion of sleeve. Taper thread on outside.
- Water jacket—
  - Material: Aluminum alloy.
  - Construction: Flanged at upper and lower ends.
  - How fastened: Bolted to cylinder head and to crank case.
- Location of water connections—
  - Inlet: At bottom of water jacket (exhaust side).
  - Outlet: To inlet manifolds through cored passages.
- Other features: The center of the head of the sleeve carries an integral stud which is drawn up inside the water jacket by a nut. There is a rubber packing ring between the lower flange on the cylinder sleeve and the internal flange on the water jacket.

Drives (see figs. 11 and 17):

Upper vertical shaft—

Construction	Inclined shaft drive gear and magneto drive gear are integral. Vertical shaft gear is keyed to shaft and retained by lock flange.
Bearings	Lower end bearing is bronze. It is pressed in the gear case. Upper end is a ball bearing located in aluminum flange plate.
Lubrication of bearings	Lower end bearing has direct feed from above No. 1 crankshaft bearing.

Inclined shaft—

Construction	Upper and lower gears keyed on the shaft and are retained by nut and cotter pin.
Bearings	Ball bearings at upper and lower ends.
Lubrication	By oil from cam shafts.

Lower vertical shaft—

Construction	Lower vertical shaft gear and worm for gasoline pump are integral with shaft. Oil pump drive shaft drive gear is keyed to shaft.
Bearings	Bronze bushings which are pressed in gear case.
Lubrication	Oil from drip pan and partially from above.

Valves (see fig. 12):

Number per cylinder	Two inlet—two exhaust.
Location	In cylinder head.
Type	Tulip.
Material	Tungsten steel.
Spring collars are retained on valve stem.	By castellated tapered sleeve threaded on the valve stem and cottered to it.
Interchangeable valves	Yes.

Valve springs—

Number per cylinder	Two.
Type	Concentric coil.
Material	Alloy steel.
Interchangeable	Yes.

Valve gear (see fig. 13):

Cam shafts	Separate inlet and exhaust shaft for each bank.
Material	Low carbon steel.
Construction	Integral forging.
Form of cams	Constant acceleration and retardation.
Boring and oil passage	Counterbored and plugged to form oil passage.
Camshafts interchangeable	Right and left are interchangeable.

Cam shaft housing—

Material	Aluminum alloy.
Construction	Aluminum casting.
Retained in place	By studs and nuts.
Number and material of cam shaft bearings.	Six supporting brackets of aluminum alloy to each bank of cylinders.

NOTE.—The cam followers are tee shaped yokes, each operating a pair of valves. The stem of the cam follower slides in a bronze guide. The tappet clearance is adjusted by means of a tappet screw in each end of the yoke locked by a clamp screw.

Valve timing adjustment: There are 10 holes in the cam shaft drive gear which is fastened to the inlet cam shaft with 5 studs. One tooth on the cam shaft gear is equivalent to 20° of crank shaft rotation. Rotating the cam shaft gear (disengaged) one bolt hole without moving the crank shaft gives a valve timing adjustment of 4°.

Lubrication system:

Pressure oil pump—

Number	One.
Type	Gear.
Material (gears)	One bronze, one steel.

Lubrication system—Continued.

Scavenging oil pumps—

Number	Two (using a common gear).
Type	Gear.
Material (gears)	Two bronze, one steel.

Strainer—

Number	One.
Type	Fine mesh screen reinforced against collapse from suction.

Relief valves—

Number	One.
Type	Spring operated, conical seat.
Location	In lower part of mounting flange of oil pump.
How reached for adjustment	From outside.
How adjusted	By washers in rear of spring.

MAIN PRESSURE CIRCUIT.

The oil is drawn through the screen around the pressure pump, which is situated in the sump reservoir in the bottom of the lower crankcase. The pump is driven by a horizontal shaft from the vertical accessory shaft. The oil is discharged by the pressure pump past the pressure relief valve to the external pressure line. It is taken to a flange connection at the upper half of the crankcase at No. 4 web on the left side. This external pipe connects with the oil mainfold which distributes oil to the eight main bearings. From here oil is led through tubes in the crankshaft to the crankpins and through metering holes lubricates the bearings. There is a direct feed by an oil tube to the hinge pin bearing from the crankpin. The piston pins and cylinder walls receive their lubrication by spray thrown by the cranks. Oil bypasses No. 8 main bearing and is carried by a tube to the front propeller shaft bearing.

AUXILIARY CIRCUIT.

Oil bypasses No. 1 crankshaft bearing bushing and is led through a drilled hole to the bronze bearing for the upper vertical driveshaft. From No. 1 bearing there are passages leading to external tubes which supply the camshafts, the oil going in through one camshaft and returning through the other. A hole at each camshaft journal lubricates the camshaft bearings. There are bypasses from one bearing across to the other to insure positive lubrication. Surplus oil in the cylinder head lubricates the valve stems, cam follower stems, etc. The extra oil in the cylinder head runs down the camshaft drive housing and lubricates the various drives. A baffle plate collects oil and drips it on the reduction gears. Spray from the reduction gears lubricates the thrust ball bearing on the propeller shaft.

SCAVENGING CIRCUIT.

Oil is pumped from the end sumps by scavenging pumps connected to each sump by a tube. Each scavenging pump outlet is a copper tube which carries the oil outside the screen. The oil from the cranks falls on an oil pan partition where it may run to either the forward or rear sump.

AUXILIARY LUBRICATION.

An external connection from the oil pump connects directly to the gasoline pump.

MISCELLANEOUS.

The oil reservoir is equipped with an oil gage which is calibrated in gallons. The pressure gage connection and the thermometer connection are at the mounting flange

on the left side at No. 4 web. The oil filler on the right side bypasses the drip pan to the oil reservoir. There is no provision for refilling the sump while in flight.

COOLING SYSTEM.

Water pump:
- Number.......... One.
- Type.......... Centrifugal with double shrouded vanes.
- Material (impeller and casing).......... Aluminum alloy.
- Location.......... Lower part of gear case.
- Stuffing box.......... A splined bronze bushing is screwed on the notched ball bearing housing. To tighten the gland the ball bearing housing is turned as if tightening a left-handed nut.

MAIN CIRCULATION SYSTEM.

The water leaves the pump by two outlets and connects with tapered inlet manifolds which deliver water to the lowest point of the water jacket in each cylinder. The water surrounds the cylinder sleeves and passes through drilled holes to the cylinder head. It circulates around the ports and passes to the outlet water manifolds through cored holes in the intake manifolds. From here it passes to the radiator. A drain cock is screwed in the pump cover casting.

Intake manifolds (see fig. 14):
- Number.......... Four.
- Type.......... Fan-shaped.
- Materials.......... Aluminum alloy.
- Construction.......... Castings with cored holes for water outlets.
- Type of flanges.......... One piece.
- Manifolds are removed.......... Taken off over hold-down studs after water is drawn from engine.
- Type of gaskets.......... Johns Manville service packing.

Carburetors (see figs. 14, 18, and 19):
- Number.......... Two.
- Name.......... Claudel-Hobson.
- Type.......... Double inverted.
- Manufacturer.......... Claudel Carburetor Co., Long Island City, N. Y.
- Materials—
  - Body.......... Aluminum alloy.
  - Nozzle.......... Brass.
  - Jets.......... Brass.
- Type of strainer.......... Wire mesh.
- Method of removing strainer.......... Held by brass cap.

MAIN JET SYSTEM.

Gasoline enters the carburetor at the bottom of the float chamber. It flows through the strainer and is admitted to the float chamber by the needle valve, which is operated by a conventional float mechanism. The fuel flows from the bottom of the float chamber to the main jet where it passes up into the emulsion well which contains a diffuser tube and an idling tube. The flow is then up to a horizontally drilled passage in the carburetor body communicating with the inverted, venturi-shaped discharge nozzle which is placed within the venturi-shaped choke. When the throttle is first opened a temporarily richer mixture is supplied by using the gasoline which has accumulated in the air well. This lowers the fuel level in the air well and uncovers a series of small holes in the diffuser tube. As the top of the air well is in direct communication with an air bleed from outside the carburetor, air is taken through the holes in the diffuser tube mixing with the gasoline in the emulsion well. This results in compensating for the tendency of the mixture to become richer as the throttle is opened. Adjustments of gasoline flow are made by changing the sizes of main jets and chokes and also by changing the location and sizes of the holes in the diffuser tube. The main jets can be reached for adjustment by removing a brass cap in the bottom of the air well.

IDLING SYSTEM.

The idling tube is supplied with fuel from the bottom of the emulsion well. Near the top of the tube are four small holes which are in direct communication with the air bleed and permit an emulsion of air and gasoline to be supplied to the idling nozzle through a drilled passage which is above the horizontally drilled passage to the main nozzle. The idling nozzle is placed downward through the inner venturi and passes through a slot in the barrel throttle. The idling adjustment is by means of a rod which can be screwed into this slot. The mixture is enriched by restricting the air flow. The mixture proportions for idling can also be changed by adjusting the size and number of the air bleed holes in the idling tube or by changing the size of the idling metering orifice.

AIR SYSTEM.

Air is admitted through an air scoop which is cut at 45° to the air stream from the propeller. The air passes downward through the venturi-shaped chokes. These are easily removable when the carburetor is taken apart at the flange above the float chamber. From the choke the air passes directly through the barrel throttle.

MIXTURE CONTROL.

The altitude control is based on the air bleed principle. The top of the float chamber is always in communication, by two large holes, to the air scoop. A cored passage across the top of the float chamber communicates, by drilled holes, to the horizontally drilled passages leading to the main nozzles.

The mixture control operates by admitting air to the horizontal nozzle passages, neutralizing, to a varying degree, the depression in the main gas passage and thereby reducing the flow of gasoline. The amount of air admitted to the nozzle passage is controlled by a valve consisting of a rod of varying cross section placed in an orifice between the cored passage and the outside of the carburetor.

Ignition (see fig. 15):
- Name of system.......... Berkshire.
- Type.......... Magneto.
- Manufacturer.......... Berkshire Magneto Co., Pittsfield, Mass.
- Model.......... D6-2F-ES.
- Number of magnetos.......... Two.
- Number of cylinders and plugs per cylinder fired by each magneto.......... One plug each in 12 cylinders.
- Type of magnetos.......... Inductor.
- Rotation.......... Both left hand.
- Are magnetos interchangeable.......... Yes.
- Distributors—
  - Number.......... One per magneto.
  - Location.......... Front end.
  - Type of brush.......... Brass—air gap.
- Magneto coupling.......... Rubber blocks.
- Spark advance and retard mechanism.......... Controlled from pilot's seat by rotating breaker mechanism.

Ignition—Continued.

Starting feature of magneto (battery excitation provided to insure sparking at low rotational speeds).	In the fully retarded position the battery is put in, and the magneto put out, of the circuit by means of an auxiliary contact.
Spark plugs—	
Name	A. C.
Manufacturer	Champion Ignition Co., Flint, Mich.

Auxiliaries (see fig. 16):

Gasoline pump: Gasoline is fed by a gear-driven, two-cylinder opposed plunger pump which is attached to the gear case. This pump has oil pressure from the main lubricating system maintained in its crank case to prevent gasoline leakage by the pistons. This pump is very similar to the one used on the Maybach engine.

Tachometer drives—	
Number	One.
Location	Lower part of gear case.

Airplane mounting:

Type of mounting required	Straight engine bearers.
Connections and controls—	
Carburetor controls—	
Number	Two.
Nature	Throttle and altitude control.
Location	Above engine.
Type	Thrust rods.
Tachometer connection—	
Number	One.
Location	Lower part of gear case.
Cooling system connections—	
Number—	
Inlet	Two.
Outlet	Two.
Location	Rear of engine.
Lubrication system connections—	
Number	One thermometer; one pressure gauge.
Location	On left side of engine at mounting flange.
Fuel system connections—	
Number	Two.
Location	At bottom of float chambers of carburetors.
Ignition system connections—	
Number	Two.
Location	Magnetos.

METHOD OF TEST.

The engine was connected to an electric cradle dynamometer and the following runs were made in accordance with the standard method which is completely described in Engineering Division Report, Serial No. 1507:

Two full power runs from 1,550 revolutions per minute to 2,250 revolutions per minute, by increments of 100 revolutions per minute.

One friction horsepower run through same speed range as for full power runs. (Compression pressure taken at 120 revolutions per minute.)

Two propeller load runs from 2,250 revolutions per minute to 1,550 revolutions per minute.

One hour fuel and oil consumption run at 2,250 revolutions per minute.

One mixture control run at 2,250 revolutions per minute, 2,050 revolutions per minute, and 1,750 revolutions per minute.

One water circulation run through the engine from 1,450 revolutions per minute to 2,250 revolutions per minute by increments of 200 revolutions per minute.

One water pump capacity run with free outlet.

Trials to determine starting torque with engine hot and cold.

The temperature of the oil supplied to the bearings was taken between the pressure pump and the main bearings at a flange connection on the left side of the upper half of the crank case at No. 4 web.

The oil consumption was obtained during the one-hour run. After warming up the engine and before starting this test, the sump was nearly filled with oil and the amount marked on the oil gauge. After the test enough oil was added to bring the gauge back to the same mark and the amount added was taken as the oil consumption for that period.

RESULTS OF TEST.

The test results which appear in this report were obtained from manufacturer's engine No. 4. It must be borne in mind that in laboratory tests it is possible to operate an engine under more favorable conditions than in actual service. The engine under consideration when installed in an airplane, and run by the average pilot, will not develop the power nor have the fuel economy which is recorded in the tables and curves in this report.

It will be noted that the air temperature averages 70° F. and, therefore, the power results are perhaps a little lower than would have been obtained at the standard air temperature of 60° F. The power results are not corrected for temperature as no reliable method is at present available.

The performance tables are on pages 10 to 13. The performance curves are figures 21 to 24.

Referring to the table of efficiency factors on page 10, the air standard efficiency is the theoretical thermal efficiency based on the compression ratio and computed from the following formula, where E is the efficiency and R the compression ratio:

$$E=1-\left(\frac{1}{R}\right)^{0.408}$$

The relative indicated efficiency is the ratio of the indicated thermal efficiency to the air standard efficiency. The relative brake efficiency is the ratio of the brake thermal efficiency to the air standard efficiency.

OBSERVATIONS ON TEST.

The performance of this engine during the test was good and little trouble of any kind was experienced in operation of the engine. There appeared to be a marked freedom from vibration, even for a 12-cylinder engine of this type, but under laboratory conditions it is impossible to obtain reliable observations in regard to vibration, as the engine is very rigidly mounted.

The altitude control was kept in the full rich position at all times. If it was moved toward the lean position, both power and speed dropped off rapidly. Before starting the second propeller load run, some trouble was experienced with oil fouling of the A. C. spark plugs on the outside of the two banks of cylinders. The A. C. spark plugs on the outside were then replaced by Mosler M-1 mica spark plugs and satisfactory operation was obtained during the remainder of this run. Before starting the one-hour fuel and oil consumption run, the Mosler spark plugs caused pre-ignition and were removed and replaced by A. C. spark plugs. Satisfactory operation was then obtained during this run. The paper gasket of the water jacket at the front end of the engine broke during the one hour run causing a slight leakage of water.

INSPECTION AFTER TEST.

At the completion of the standard engine tests, the Curtiss model C–12 engine was completely disassembled for inspection. The following is a report on the condition of the various parts:

BEARINGS.

All bearings showed slight babbitt loading. The white metal had flowed over the edge of No. 2 and 6 main bearings. No. 8 main bearing was unevenly worn. The dowel screws of No. 4 main bearing were broken. The lower half of No. 6 connecting rod bearing had a small piece of white metal broken away.

PISTONS.

All pistons had a fairly heavy deposit of carbon.

GEARS.

Most of the propeller gear teeth showed uneven wear. The crank shaft reduction gear had several unevenly worn teeth. The teeth on the magneto bevel driving gears were burred.

VALVES.

Both exhaust valves leaked in every cylinder when tested with gasoline. Two intake valves leaked in cylinders Nos. 2, 4, 8, 11, and 12 and one in each of the other cylinders.

WATER PUMP.

The impeller hub was cracked and loose on the shaft and the impeller had cut the aluminum housing.

IGNITION.

The insulation of the ignition wires was cut, on the outlet of the manifold, by the sharp edge of the hole.

ENGINE MOUNTING LUGS OR FLANGES.

The holes for the hold-down studs had been slightly enlarged apparently by vibration.

All other parts showed normal signs of wear incident to a test of this nature.

ANALYSIS OF ENGINE.

DESIGN.

The general design is good and the engine assembly presents a compact, clean-cut appearance. The outstanding feature is the en-bloc cylinder construction which permits cooling water in direct contact with the steel liner or cylinder sleeve, except around the combustion chamber. The method of securing good contact of the liner in the cylinder head is particularly good.

The weight, dry, per normal brake horsepower of 1.633 pounds is exceptionally low. Judged only by the operation during this test, the major parts appear to be sufficiently heavy. The most noticeable saving of weight is in the crankshaft, which has very large bores in the crankpins and the main journals.

The bronze bearing bushings lined with white metal did not stand up as well as the aluminum bearing bushings lined with white metal, which are used in the Curtiss six-cylinder, model C–6 aviation engine. This may be due to the much higher speed and heavier loading of the C–12 rod-bearing assemblies.

The four valves are so located in the cylinder head that they can not be removed without first removing the valve guides. This makes valve grinding very difficult.

Oil from around No. 1 main bearing is taken to the cam-shaft bearings. An oil hole in the rear cam-shaft bearing support registers with a hole in the cylinder head. As there is no locating dowel pin, this support can be reversed, in which case the cam-shaft bearings will get no oil. This should be corrected by the addition of a dowel pin in the bearing support.

All the thrust on the cam shaft due to the use of bevel driving gears is taken by No. 1 bearing support. This is held by two small studs which do not appear strong enough to carry the load.

ADAPTABILITY TO PRODUCTION.

The engine presents no features which could not be easily handled in quantity production.

PERFORMANCE.

The performance of the engine on the dynamometer stand was good, with the exception of the oil consumption. The oil consumption at normal horsepower of 0.0832 pound per brake horsepower hour is extremely poor and precludes the use of a sump reservoir with this engine unless provision is made to replenish the supply in the sump during flight. For a pursuit ship which is to fly one-half hour at sea level and 2½ hours at 15,000 feet, 128.7 pounds of oil would be required, whereas the total capacity of the sump is only 36.7 pounds. The high oil consumption probably accounts for the fouling of the spark plugs, on the outside, during the propeller load run. Oil leakage past the very narrow main bearings between cylinders 1 and 2, 3 and 4, and 5 and 6 probably accounts in a large measure for this high consumption.

The full power curve peaks at 2,300 revolutions per minutes of the engine, at which speed the engine develops 425 brake horsepower. The brake mean effective pressure at normal speed of 131.3 pounds per square inch is excellent and is maintained fairly constant, thus indicating a high volumetric efficiency throughout the speed range. The maximum brake mean effective pressure, 137 pounds per square inch, is obtained at 1,750 revolutions per minute of the engine.

The specific fuel consumption at full throttle and normal speed of 0.503 pound per (actual) brake horsepower hour is good. The specific fuel consumption on propeller load increases rapidly as the throttle is closed. Since an engine in service operates most frequently at partial throttle, the average specific fuel consumption would be very much higher than it is at normal speed. A characteristic of the usual type Claudel-Hobson carburetor is to give practically as low specific fuel consumption on propeller load as at full power operation. The Claudel-Hobson inverted carburetor used on this engine departs from the usual construction in the use of a double venturi jet assembly. This double venturi is probably responsible for the rapid increase of specific fuel consumption on propeller load operation at the lower speeds.

The output of 0.373 brake horsepower per cubic inch of piston displacement at the normal speed is unusually

high, due to the high speed and brake mean effective pressure at which the engine operates.

ADAPTABILITY TO AIRPLANE.

This engine provides for straightforward mounting, requiring only two engine bed timbers. It is possible to slide the engine in and out on the bed timbers. The head resistance is not great.

ACCESSIBILITY.

The accessibility of all parts and accessories for adjustment and inspection is good. The carburetors can be reached for adjustment from above the engine. The magnetos can be reached through openings at the sides of the engine cowling. The outside spark plugs are easily reached for replacements. The inside spark plugs are not so conveniently located but are easily removed, as there is no interference with the carburetors. The water pump, tachometer, gasoline pump, and adjustable oil pressure relief valve can be easily reached for adjustments through openings properly located in the engine cowling.

MAINTENANCE.

The construction of the engines is such that overhauling can not be done without a considerable expenditure of time as compared with other engines. For instance, the valves can not be ground without removal of the valve guides which is an operation requiring special tools and more than average care. The clearance provided around many of the studs is insufficient to permit turning the nuts with socket wrenches. Many of the aluminum flanges on the engine are so thin as to be subject to breakage in handling or in drawing up on the bolts.

CARBURETORS.

The carburetors are unsatisfactory due to their high fuel consumption on propeller load and to the fact that they have several external air vents. These external vents entail some fire risk and preclude the use of a supercharger. It has been found that the type of mixture control used is unsatisfactory. Provision should be made so that in case of flooding of the carburetors, gasoline does not drain into the engine.

SUMMARY.

The test shows the need of improvement in the following details of the engine:

Valve design: To allow of removing valves without pulling guides.

Water pump: To strengthen hub of impeller.

Ignition wiring manifold: To prevent cutting of high-tension wire insulation.

Gear end cam-shaft bearings: To preclude possibility of assembling incorrectly, so as to cut off oil supply to cam shaft, and to provide more positive holding against end thrust of cam-shaft gears.

Bearings and lubrication system: To reduce oil consumption to a reasonable quantity.

Carburetors: To give better fuel economy on propeller load, to incorporate a more practical type of mixture control, to eliminate all external air vents, and to prevent filling up cylinders in case of flooding.

Bolt bosses and flanges.—To be more rugged and to allow clearance for use of socket wrench.

It is also believed that the lubrication of the reduction gears should be by a positive jet under pressure.

Since the Engineering Division is not interested in a geared engine of this size which can not be adapted to a cannon mounting, further tests on this engine are not contemplated. A direct drive model is being developed at the present time.

WEIGHTS OF CURTISS MODEL C-12 ENGINE AND PARTS.

		Weight (pounds).	Per cent of total.
Crank-case group, complete with bearings, studs, nuts, and breathers, including:			
1 upper half.....pounds..	92.0		
1 lower half.....do....	35.3		
Total.....		127.3	18.24
Crank-shaft group, complete, with crank-shaft gear, reduction driving gear, oil tubes, etc.....		61.3	8.78
Propeller shaft assembly, complete with ball bearing, reduction gear, and propeller hub rear flange.		40.0	5.73
Propeller hub assembly, front flange and bolts only.....		15.0	2.15
Connecting-rod group, including 6 connecting-rod assemblies averaging 6.05 pounds each.....		36.3	5.20
Piston group, including 12 piston assemblies complete with rings and pin, averaging 2.17 pounds each.....		26.0	3.73
Cylinder group, including 2 cylinder blocks, of 6 cylinders each, complete with valves, valve springs, valve guides, and breathers.....		203.5	29.16
Driving-gear group, including:			
2 cam-shaft drive shafts and housings.....pounds..	9.0		
Gear case with magneto brackets.....do....	12.2		
Upper vertical drive shaft and gears.....do....	3.3		
Lower vertical drive shaft and gears.....do....	1.0		
Oil pump drive.....do....	1.0		
2 magneto drive couplings and tachometer drive.....do....	3.2		
Total.....		29.7	4.26
Cam-shaft group, including:			
4 cam-shafts complete with gears and bearings.....pounds..	28.3		
2 cam-shaft housings, complete....do....	15.5		
24 cam followers.....do....	6.8		
Total.....		50.6	7.25
Lubrication group, including:			
1 oil pump assembly.....pounds..	6.0		
Oil manifold and piping.....do....	2.6		
Total.....		8.6	1.23
Cooling system, including:			
Water pump assembly.....pounds..	3.9		
Water manifolds.....do....	7.5		
Total.....		11.4	1.63
Carburetor and intake group, including:			
2 double carburetors.....pounds..	18.8		
4 intake manifolds.....do....	16.2		
Total.....		35.0	5.01
Ignition group, including:			
2 magneto assemblies.....pounds..	33.0		
Ignition wires and headers with distributor covers.....do....	10.0		
24 spark plugs.....do....	4.0		
Total.....		47.0	6.73
Miscellaneous, cotter pins, wire, nuts, etc.....		6.3	.90
Total weight, without auxiliaries.....		698.0	100.00
Auxiliaries:			
1 gasoline pump.....pounds..	3.6		
Storage battery for starting.....do....	10.5		
Total.....		14.1	.....
Total weight of engine, with auxiliaries.....		712.1	.....
Weight of water in engine.....		37.0	.....

TABLE OF DIMENSIONS.

General:
- Bore.................................... 4.500 in.
- Stroke.................................... 6.000 in.
- Compression ratio........................ 5.5:1.
- Gear ratio (propeller speed to engine speed).................................. 3:5.
- Rotation of propeller (facing propeller). Counter-clockwise.
- Total piston displacement.............. 1,145.0 cu. in.
- Approximate head resistance area....... 4.597 sq. ft.
- Firing order.............................. 1-6-7-10-3-2-11-8-5-4-9-12.
- Method of numbering cylinders........ From magneto end; even numbers on right, odd numbers on left.

Crank case:
- Distance between centers of cylinders No.—
  - 1-2.................................. 5.187 in.
  - 2-3.................................. 6.000 in.
  - 3-4.................................. 5.187 in.
  - 4-5.................................. 6.000 in.
  - 5-6.................................. 5.187 in.
- Diameter main bearing studs........... Inside rows $\frac{7}{16}$ in.
  - Do.................................. Outside rows $\frac{5}{8}$ in.
- Capacity of oil sump.................... 5 U. S. gallons.
- Main crank shaft bearings—

No.	Diameter.	Length.	Diametral clearance.	End clearance.	Projected area.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Sq. in.*
1..........	3.002	1.950	0.002	0.035	5.856
2, 4, 6......	3.002	1.231	.002	.085	3.695
3, 5........	3.002	2.000	.002	.125	6.006
7..........	3.002	2.877	.002	....	8.640
8..........	3.002	1.629	.002	....	4.892

- Engine hold-down bolts—
  - Number............................ Ten.
  - Diameter.......................... $\frac{5}{8}$ in.

Crank shaft:

No.	Outside diameter.	Length.	Diameter bore.
Main journals—	*Inches.*	*Inches.*	*Inches.*
1..............................	3.000	1.985	2.500
2, 4, 6..............................	3.000	1.316	2.500
3, 5..............................	3.000	2.125	2.500
7..............................	3.000	3.440	2.500
8..............................	3.000	2.656	2.500
Crank pins—			
1, 2, 3, 4, 5, 6....................	2.500	2.142	1.875

- Crank cheeks—
  - Width.................................. 3.500 in.
  - Thickness.............................. 0.847 in.

Reduction gear:
- Ratio propeller speed to crank-shaft speed.. 3:5.
- Circular pitch of gears.................... 0.6185 in.
- Tooth form.................................. Herringbone.
- Backlash.................................... 0.003 in.
- Crank-shaft gear—
  - Number of teeth........................ 30.
  - Face width.............................. 2.191 in.
- Propeller-shaft gear—
  - Number of teeth........................ 50.
  - Face width.............................. 2.191 in.
- Journal—
  - Outside diameter........................ 2.500 in.
- Propeller-shaft bearings—

	Diameter.	Length.	Diametral clearance.
	Inches.	*Inches.*	*Inches.*
Front............................	2.502	4.007	0.002
Rear............................	None.	....	....

Reduction gear—Continued.
- Thrust bearing—
  - Number of balls........................ 8.
  - Diameter of balls........................ 0.875 in.
  - Diameter of ball circle.................. 4.000 in.
  - Manufacturer............................ Hess-Bright.
  - Manufacturer's No...................... 8313.

Propeller hub:
- Diameter hub body........................ 2.188 in.
- Length between flanges—
  - Minimum................................ 5.750 in.
  - Maximum................................ 7.375 in.
- Diameter bolt circle........................ 8.125 in.
- Bolts—
  - Number.................................. 8.
  - Minimum outside diameter............ 0.625 in.
  - Maximum outside diameter............ 0.765 in.
  - Bore...................................... 0.375 in.
  - Thread.................................... 18 threads per inch.

Connecting rods:
- Length of main rod, center to center....... 10.000 in.
  - Number of bolts to hold cap........... Four.
- Minimum diameter of shank (bolts)....... 0.311 in.
- Thread (bolts)............................ $\frac{3}{8}$-inch, 24 threads per inch.
- Length of articulated rod, center to center.. 7.750 in.
  - Number of bolts to hold hinge pin..... One.
- Minimum diameter of shank (bolts)....... 0.311 in.
- Thread (bolts)............................ $\frac{3}{8}$-inch, 24 threads per inch.
- Rod-stroke ratio............................ 1.667:1.
- Piston-pin bushing—
  - Length.................................. 1.630 in.
  - Diameter, inside........................ 1.126 in.
  - Projected area........................ 1.836 sq. in.
  - End play of rod........................ 0.124 in.
  - Clearance to pin........................ 0.001 in.
- Big end bearing, main rod—
  - Length.................................. 2.125 in.
  - Diameter................................ 2.502 in.
  - Clearance on crank pin—
    - Diametral.......................... 0.002 in.
    - End.................................. 0.017 in.
  - Projected area on crank pin........... 5.315 sq. in.
- Hinge-pin bushing, articulated rod—
  - Length (total).......................... 1.330 in.
  - Diameter................................ 1.127 in.
- Diametral clearance on hinge pin.......... 0.002 in.

Pistons:
- Area of head................................ 15.91 sq. in.
- Distance from center of pin to top of piston. 1.625 in.
- Length over all............................ 3.750 in.
- Clearance in cylinder—
  - Top...................................... 0.021 in.
  - Bottom.................................. 0.018 in.
- Rings—
  - Number per piston...................... 3.
  - Tension.................................. 5 lb.
  - Width—
    - Two upper rings.................... 0.125 in.
    - One lower ring...................... 0.094 in.
- Width of gap (ring in cylinder)............ 0.010 in.
- Pin—
  - Length.................................. 3.928 in.
  - Diameter................................ 1.125 in.
  - Diameter bore, ends.................... 0.925 in.
  - Diameter bore, center.................. 0.797 in.
  - Total length of bearing in piston...... 2.174 in.

Cylinders:
- Bore... 4.500 in.
- Stroke....................................... 6.000 in.
- Stroke-bore ratio........................... 1.333:1.
- Piston displacement per cylinder.......... 95.40 cu. in.
- Total piston displacement of engine....... 1,145 cu. in.
- Compression volume of cylinder........... 21.19 cu. in.
- Total volume of cylinder.................. 116.59 cu. in.
- Compression ratio.......................... 5.5:1.
- Per cent compression...................... 18.18 per cent.

Cylinders—Continued.

Port openings—

	Intake.	Exhaust.
Number per cylinder	2	2.
Shape	Elipse	Elipse.
Height	1.500 in	1.500 in.
Width	1.750 in	1.750 in.
Number of studs	20 studs to 12 ports	

Water connections—

	Number.	Inside diameter.
		Inch.
Inlet	6	0.625
Outlet	6	0.625

Hold-down studs per cylinder—

Number.	Diameter.	Threads per inch.
	Inch.	
4	7/16	24

Cam shafts (four):

Outside diameter .... 1.003 in.

Journals—

Number.	Diameter.	Length.
	In.	*In.*
6	1.061	1.500

Bearings—

Number.	Diameter.	Length.
	In.	*In.*
6	1.064	1.500

Cams—

Body diameter.	Width.	Lift.
	In.	*In.*
Intake, 1.124 inches	0.570	0.417
Exhaust, 1.124 inches	0.570	0.417

Valves:

Inlet and exhaust valves—

- Number of each per cylinder .... Two.
- Outside diameter .... 1.800 in.
- Inside diameter of seat .... 1.628 in.
- Lift .... 0.402 in.
- Angle of seat .... 45°.
- Angle of stem with cylinder axis .... Parallel.
- Total area of opening (each valve) .... 1.646 sq. in.
- Stem diameter .... 0.343 in.
- Tappet clearance .... 0.015 in.

Valve springs—

- Number per valve .... Two.
- Tension inlet (both springs)—
  - Valve open .... 42.0 lb.
  - Valve closed .... 27.0 lb.

Valves—Continued.

Valve springs—Continued.

- Tension exhaust (both springs)—
  - Valve open .... 42.0 lb.
  - Valve closed .... 27.0 lb.
- Internal spring tension—
  - Valve closed .... 20.5 lb.
  - Valve open .... 29.0 lb.

Valve timing—

	Actual.	Designed.
Inlet:		
Opens	1° late	
Closes	46° late	42° late.
Exhaust:		
Opens	58° early	58° early.
Closes	6° late	

Oil pump (gear type):

	Pressure.	Scavenging.
Number	One	Two (using a common gear).
Material, casing	Aluminum alloy	Alluminum alloy.
Material, gears	1 steel, 1 bronze	1 steel, 2 bronze.
Speed	Crank-shaft	Crank-shaft.
Number of gears	Two	Three.
Pitch diameter, gears	1.250 in	1.250 in.
Number of teeth	10	10.
Face width	0.743 in	0.743 in.

Water pump:

Material—

- Housing .... Aluminum alloy.
- Impeller .... Aluminum alloy.

Type .... Centrifugal.

Speed .... 1½ crank-shaft speed.

Diameter impeller .... 4.000 in.

Number of vanes .... 8 (shrouded).

Number of inlets—inside diameter .... One (1½ in.).

Number of outlets—inside diameter .... Two (13/16 in.).

Diameter shaft .... 0.567 in.

Water connections to engine—

- Number of inlets—inside diameter .... One (1½ in.).
- Number of outlets—inside diameter .... Two (1 1/16 in.).

Carburetors:

- Number .... Two double inverted.
- Material, body .... Aluminum alloy.
- Diameter at the flange, inside .... 2.000 in.
- Chokes diameter .... 1.458 in.
- Metering jets, material .... Brass.
- Diameter main jet .... 42 drill size.
- Diameter idling jet .... 71 drill size.

Ignition:

- Maximum spark advance .... 30° before top center.
- Maximum retard .... 6° after top center.
- Number of magnetos .... Two.
- Speed, pole pieces .... 1½ crank-shaft speed.
- Speed, distributor .... ½ crank-shaft speed.
- Width of breaker gap .... 0.020 in.

Spark plugs:

- Size of thread .... 18 mm. diameter—1.5 mm. pitch (S. A. E. metric).
- Gap .... 0.017 in.

Auxiliaries:

Gasoline pump—

- Speed .... ½ crank-shaft speed.
- Bore .... 1.015 in.
- Stroke .... 0.563 in.
- Inside diameter inlet .... 0.375 in.
- Inside diameter outlet .... 0.375 in.

Tachometer drive connection—

- Speed .... 1½ crank-shaft speed.
- Outside diameter threads .... 0.868 in.
- Thread .... 18 threads per inch.

EFFICIENCY FACTORS FOR CURTISS MODEL C-12 AVIATION ENGINE AT NORMAL ENGINE SPEED OF 2,250 REVOLUTIONS PER MINUTE.

Cubic inches of piston displacement per b. hp....	2.680 cu. in.
B. hp. per cubic inch of piston displacement...	0.373 b. hp.
B. hp. per cubic foot of piston displacement.....	645.0 b. hp.
B. hp. per square foot of piston area..........	322.5 b. hp.
Piston speed in feet per minute...............	2,250 ft. per min.
Indicated mean effective pressure..............	151.8 lb. per sq. in.
Friction mean effective pressure...............	20.5 lb. per sq. in.
Brake thermal efficiency [1].....................	24.05 per cent.
Indicated thermal efficiency [1]..................	27.80 per cent.
Air standard efficiency.........................	50.12 per cent.
Relative indicated efficiency...................	55.50 per cent.
Relative brake efficiency.......................	48.05 per cent.
Mechanical efficiency...........................	86.40 per cent.
Weight per cubic inch of piston displacement..	0.6095 lb.

[1] Based on a fuel heat content of 21,000 B. T. U. per pound.

POWER PLANT WEIGHT BY CLASS OF SERVICE (POUNDS).

Weight factors.	Pursuit.[1]	Two-place.[2]	Training.[3]
Engine weight, dry................	702.0	702.0	702.0
Power plant constant weight...........	104.6	104.6	104.6
Cooling system..................	277.8	277.8	277.8
Tankage..........................	191.0	304.6	226.3
Fuel.............................	418.3	711.7	451.8
Oil..............................	128.7	182.0	110.9
Total........................	1,822.4	2,282.7	1,873.4
Per horsepower..................	4.264	5.341	4.383

[1] ½ hour at sea level, 2½ hours at 15,000 feet.
[2] ½ hour at sea level, 4 hours at 10,000 feet.
[3] 2½ hours at sea level.

Altitude.	Horsepower (see curve, fig. 23).	Fuel consumption lb. per hr.
Sea level..........................	427.4	214.6
10,000 feet.........................	278.6	151.1
15,000 feet.........................	214.4	124.4

FULL POWER RUNS.

FIRST RUN.

Eng. r. p. m.	Actual.		Corrected.			Water.		Oil.			Carb. air, temp. °F.	Man. vac., in. Hg.	Float chamber vac., in. water.	Fuel cons.		
	Brake load, lb.	B. hp.	Crankshaft torque, lb. ft.	Hp.	B. m. e. p., lb. per sq. in.	Temp. °F. In.	Temp. °F. Out.	Temp. °F. Sump.	Temp. °F. Bearings.	Press., lb. per sq. in.				Sec. for 5 lb.	Lb. per hp. hr.	Lb. per hr.
1,554......	952	295.9	1,030	305.0	135.6	144	166	79	138	85	70	1.0	2.0	111.6	0.545	161.2
1,661......	956	317.4	1,034	327.2	136.2	136	156	81	140	87	70	1.1	2.3	108.2	0.525	166.5
1,753......	962	337.5	1,041	348.0	137.1	140	164	86	145	87	70	1.2	2.7	103.2	0.517	174.4
1,870......	968	358.3	1,036	369.4	136.4	138	158	86	150	88	70	1.3	3.0	98.4	0.511	183.0
1,950......	949	370.4	1,026	381.5	135.2	138	160	88	152	88	70	1.5	3.4	96.8	0.502	185.9
2,050......	941	385.8	1,018	397.8	134.2	138	162	91	158	89	70	1.7	3.8	93.0	0.502	193.6
2,167......	928	402.2	1,004	414.6	132.3	140	162	93	160	88	70	1.8	4.1	90.4	0.496	199.4
2,283......	906	413.7	981	426.5	129.2	140	160	95	158	85	70	1.9	4.4	87.2	0.499	206.5

Barometer, 29.01 in. Hg.

SECOND RUN.

Eng. r. p. m.	Actual.		Corrected.			Water.		Oil.			Carb. air, temp. °F.	Man. vac., in. Hg.	Float chamber vac., in. water.	Fuel cons.		
	Brake load, lb.	B. hp.	Crankshaft torque, lb. ft.	Hp.	B. m. e. p., lb. per sq. in.	Temp. °F. In.	Temp. °F. Out.	Temp. °F. Sump.	Temp. °F. Bearings.	Press., lb. per sq. in.				Sec. for 5 lb.	Lb. per hp. hr.	Lb. per hr.
1,567......	939	294.3	1,018	303.7	134.2	138	160	77	130	85	70	0.9	1.9	112.0	0.545	160.7
1,667......	953	317.7	1,032	327.7	135.9	138	160	79	128	85	70	1.0	2.2	110.0	0.516	163.9
1,750......	949	332.3	1,028	342.8	135.5	140	162	81	132	85	70	1.2	2.5	104.2	0.520	172.7
1,850......	954	353.1	1,033	364.2	136.1	138	160	82	145	87	70	1.3	2.7	100.6	0.507	178.9
1,983......	952	377.6	1,031	389.5	135.8	138	158	84	150	88	70	1.5	3.0	96.0	0.497	187.6
2,050......	944	387.0	1,023	399.1	134.8	140	160	86	155	88	70	1.7	3.4	94.6	0.492	190.3
2,150......	922	396.5	998	409.0	131.5	140	160	90	160	87	72	1.8	3.7	91.0	0.499	197.8
2,250......	902	406.0	977	419.0	128.7	140	160	95	163	85	74	1.9	4.1	88.8	0.499	202.6

Barometer, 29.01 in. Hg.
NOTE.—The best setting for the altitude control was found to be in the full rich position.

PROPELLER LOAD RUNS.

FIRST RUN.

Eng. r. p. m.	Actual. Brake load, lb.	Actual. B. hp.	Corrected. Crank-shaft torque, lb. ft.	Corrected. Hp.	Water. Temp. °F. In.	Water. Temp. °F. Out.	Oil. Temp. °F. Sump.	Oil. Temp. °F. Bearings.	Oil. Press., lb. per sq. in.	Carb. air temp. °F.	Man. vac., in. Hg.	Float chamber vac., in. water.	Fuel cons. Sec. for 5 lb.	Fuel cons. Lb. per hp. hr.	Fuel cons. Lb. per hr.
2,267	914	414.7	989	427.4	136	163	95	152	92	70	2.0	4.2	85.0	0.511	211.9
2,150	813	349.6	880	360.1	136	158	99	161	87	70	3.7	3.4	99.2	0.519	181.4
2,017	735	296.6	796	305.5	138	158	99	160	85	70	5.0	2.7	110.6	0.549	162.8
1,950	672	261.6	728	269.5	140	160	99	152	87	70	5.7	2.0	120.0	0.574	150.2
1,833	598	219.3	647	225.9	141	159	100	149	85	70	6.7	1.4	130.2	0.631	138.3
1,767	548	193.7	593	199.5	143	160	99	142	85	72	7.4	0.6	136.0	0.684	132.4
1,633	489	159.7	529	164.4	144	159	77	130	88	78	9.5	0.0	148.6	0.759	121.1
1,533	437	134.0	473	138.0	147	157	77	132	84	80	10.5	0.0	157.6	0.853	114.2

Barometer, 29.04 in. Hg.

SECOND RUN.

Eng. r. p. m.	Actual. Brake load, lb.	Actual. B. hp.	Corrected. Crank-shaft torque, lb. ft.	Corrected. Hp.	Water. Temp. °F. In.	Water. Temp. °F. Out.	Oil. Temp. °F. Sump.	Oil. Temp. °F. Bearings.	Oil. Press., lb. per sq. in.	Carb. air temp. °F.	Man. vac., in. Hg.	Float chamber vac., in. water.	Fuel cons. Sec. for 5 lb.	Fuel cons. Lb. per hp. hr.	Fuel cons. Lb. per hr.
2,250	912	410.6	988	423.5	136	160	82	148	92	82	2.0	4.1	90.4	0.485	199.2
2,133	827	352.9	896	363.9	148	164	88	162	85	82	3.4	3.4	102.0	0.500	176.4
2,050	756	309.9	819	319.5	144	161	86	162	85	81	4.6	2.5	107.8	0.539	167.0
1,967	679	267.2	735	275.5	140	157	86	160	85	82	5.8	1.9	115.8	0.581	155.2
1,850	615	227.6	666	234.7	140	157	84	158	83	82	7.0	1.3	125.2	0.632	143.8
1,750	551	192.8	597	198.8	145	162	82	152	83	83	8.3	0.7	134.6	0.694	133.8
1,650	491	162.0	532	167.0	145	160	79	146	81	82	9.3	0.2	147.6	0.753	121.9
1,550	435	134.8	471	139.0	147	160	79	140	81	82	10.2	0.0	163.6	0.817	110.2

Barometer, 29.02 in. Hg.

ONE HOUR FUEL AND OIL CONSUMPTION RUN.

Engine r. p. m.	Actual. Brake load, lb.	Actual. B. hp.	Corrected. Crank-shaft, torque, lb. ft.	Corrected. Hp.	Corrected. B. m. e. p., lb. per sq. in.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. Sump.	Oil. Temp., °F. Bearings.	Oil. Press., lb. per sq. in.	Carb. air temp., °F.	Man. vac., in. Hg.	Float vac., in. Hg.	Fuel cons. Scale reading, lb.	Fuel cons. Lb. per hp. hr.
....	931	....	1,008	....	132.8	132	156	90	148	94	63	2.0	0.3	86.0	....
2,233	926	413.5	1,002	426.5	131.9	138	162	95	165	85	64	2.0	0.3	68.8	0.499
2,237	922	412.5	1,000	425.5	131.7	137	158	97	168	82	64	2.0	0.3	51.5	0.503
2,240	918	411.5	995	424.5	131.0	136	160	97	171	80	64	2.0	0.3	34.0	0.510
2,233	916	409.0	993	422.0	130.8	138	162	99	171	80	65	2.0	0.3	113.4	....
2,223	918	408.1	995	421.0	131.0	136	160	100	170	82	67	2.0	0.3	96.4	0.500
2,227	918	408.9	995	421.9	131.0	135	160	104	170	83	67	2.0	0.3	79.2	0.505
2,230	918	409.5	995	422.5	131.0	137	160	75	152	89	68	2.0	0.3	62.0	0.504
2,230	917	409.2	994	422.3	130.9	138	160	73	147	93	68	2.0	0.3	44.8	0.505
2,230	918	409.5	995	422.5	131.0	136	160	86	165	85	66	2.0	0.3	114.7	....
2,230	920	410.5	998	423.5	131.4	137	160	95	169	83	66	2.0	0.3	97.7	0.497
2,227	922	410.7	1,000	423.7	131.7	135	160	97	170	82	67	2.0	0.3	80.7	0.497
2,217	918	407.0	995	419.9	131.0	134	.159	97	170	82	66	2.0	0.3	63.5	0.507

AVERAGE RESULTS.

2,230	920	410.5	998	423.5	131.5	136	159	93	164	85	66	2.0	0.3	[1] 171.8	0.503

[1] For 50 minutes.

NOTE.—37 pounds of oil was used in 65 minutes, giving a specific oil consumption of 0.0832 lb. per hp. hr.
Readings were taken every five minutes. Average barometer, 29.00 in. Hg.
Data for all runs: Length of brake arm, 21 inches; kind of oil used, 75 per cent castor, 25 per cent Mobiloil B; specific gravity, gasoline, 0.710 at 60° F.

FRICTION HORSEPOWER AND COMPRESSION PRESSURE RUN.

Engine r. p. m.	Propeller r. p. m.	Corrected engine b. h. p. (from curve) (fig. 21).	Friction load, lb.	Friction horsepower.	Friction m. e. p., lb. per sq. in.	Per cent mechanical efficiency.	Cylinder No.	Comp. press., lb. per sq. in.[1]
1,550	930	303	103	31.9	14.23	90.5	1	104
1,650	990	322	110	36.3	15.21	89.9	2	108
1,750	1,050	344	116	40.6	16.04	89.5	3	102
1,850	1,110	364	122	45.2	16.89	89.0	4	107
1,950	1,170	383	127	49.6	17.58	88.5	5	107
2,050	1,230	399	131	53.8	18.14	88.1	6	122
2,150	1,290	412	139	59.8	19.22	87.4	7	106
2,250	1,350	422	148	66.6	20.46	86.4	8	108
							9	106
							10	108
							11	107
							12	110

[1] The compression pressure was taken at 120 r. p. m. (engine speed).

NOTE.—This friction horsepower run was made immediately after the second propeller load run. The water and oil temperatures were maintained the same as during that run.
Length of brake arm, 21 inches; oil used, 75 per cent castor, 25 per cent Mobiloil B; room temperature, 77° F.

MIXTURE CONTROL RUN.[1]

Positions of altitude cont.	R. p. m.	Actual.		Corrected.			Water.		Oil.			Carb. air, temp. °F.	Man. vac., in. Hg.	Float chamber, vac. in. water.	Fuel cons.	
		Brake load, lb.	B. hp.	Torque, lb. ft.	Hp.	B. m. e. p., lb. per sq. in.	Temp. °F. In.	Temp. °F. Out.	Temp. °F. Sump.	Temp. °F. Bearings.	Press., lb. per sq. in.				Sec. for 5 lb.	Lb. per hp. hr.
Full rich	2,250	912	410.6	989.0	423.7	130.3	137	159	99	125	103	66	2.0	4.1	85.8	0.511
Full rich	[1] 2,050	760	311.6	824.0	321.6	108.6	138	158	88	159	85	66	4.5	2.7	108.8	0.531
Full rich	[1] 1,767	657	232.2	712.0	239.6	93.8	142	160	84	150	83	66	6.6	1.4	123.6	0.628
Full lean	2,250	880	398.1	954.0	408.9	125.6	138	160	99	161	87	66	2.0	4.1	98.6	0.461
Full lean	[1] 2,050	744	305.1	806.5	314.9	106.3	140	161	90	158	85	66	4.6	2.8	118.0	0.500
Full lean	[1] 1,767	647	228.7	701.5	235.9	92.4	142	160	82	147	84	66	6.8	1.4	134.6	0.585

[1] Engine throttled as on propeller load operation.

Average barometer, 28.99 in. Hg.
Data for all runs: Kind of oil, 75 per cent castor, 25 per cent Mobiloil B; specific gravity gasoline, 0.710 at 60° F.; length of brake arm, 21 inches.

WATER CIRCULATION RUN THROUGH ENGINE.

Engine r. p. m.	Water temp. °F. tank.[1]	Flow through engine.		
		Measured flow. Pounds.	Measured flow. Seconds.	Gallons per minute.
1,450	114	177.5	25.8	49.9
1,650	110	173.6	21.6	58.2
1,850	103	172.5	19.2	65.2
2,050	107	171.5	17.6	70.7
2,250	109	173.7	16.6	75.8

[1] Discharge into measuring tank.

NOTE.—One gallon of water at 108° F. weighs 8.28 lb.

STARTING TORQUE.

Engine cold.					Engine warm.				
Throttle.	Starting torque—lb. ft. 1 [2]	2 [2]	3 [2]	Average.	Throttle.	Starting torque—lb. ft. 1 [2]	2 [2]	3 [2]	Average.
Open	250.2	225.8	224.0	233.3	Open	257.3	259.0	253.8	256.7
Closed	259.0	252.0	271.3	260.8	Closed	174.7	253.8	253.8	227.4

Trial number.

WATER PUMP CAPACITY RUN, FREE INTAKE AND DISCHARGE.

Speed r. p. m.		Drive torque,[1] lb. ft.	Drive horse-power.	Flow.	
Pump.	Engine (crank-shaft).			Sec. for 200 lb.	Gallons per minute.
2,325	1,550	1.5	0.665	19.6	73.5
2,625	1,750	1.9	0.950	17.6	82.0
2,925	1,950	2.3	1.282	15.8	91.3
3,225	2,150	2.7	1.659	14.2	101.5

[1] 12-inch arm.

NOTE.—Maximum pressure at normal engine speed of 2250 r. p. m. is 20 lb. per sq. in.

96726—22——3

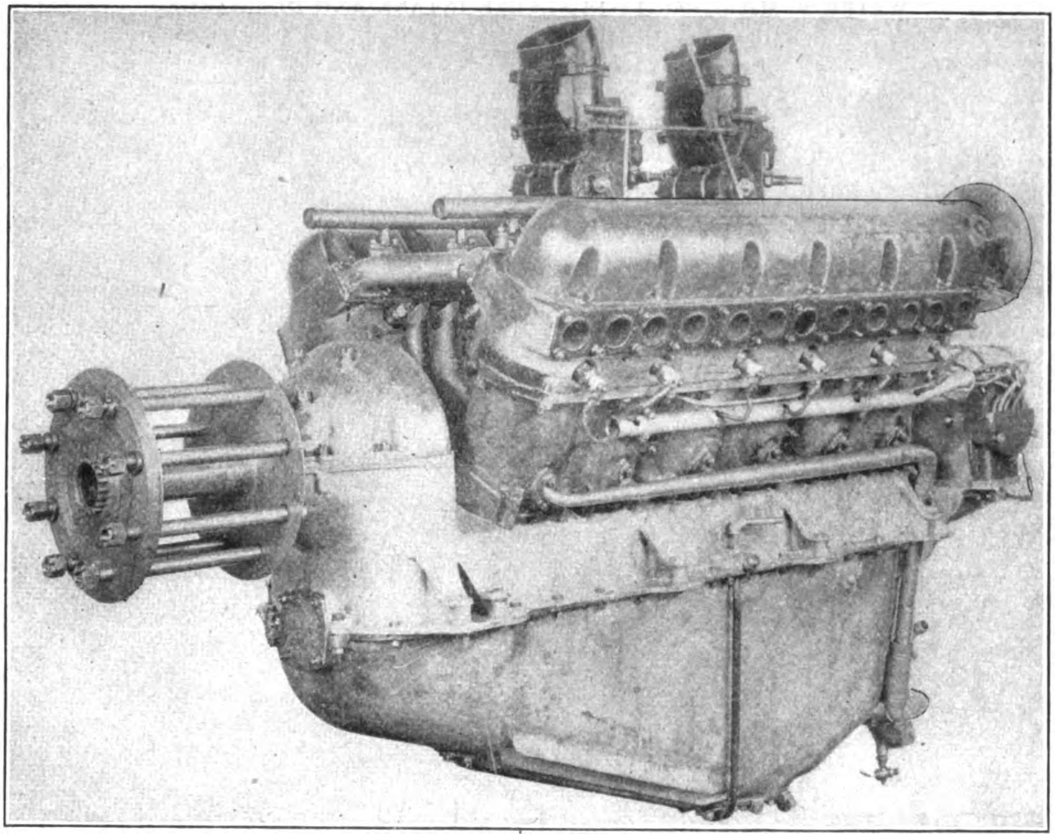


FIG. 1.—Three-quarter view (front and left side).

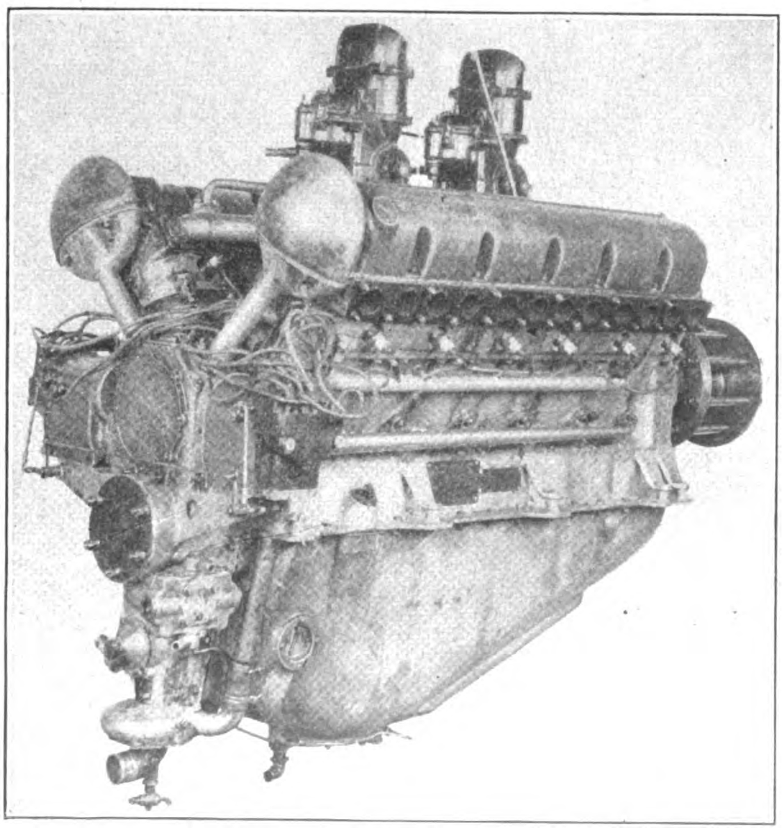


FIG. 2.—Three-quarter view (rear and right side).

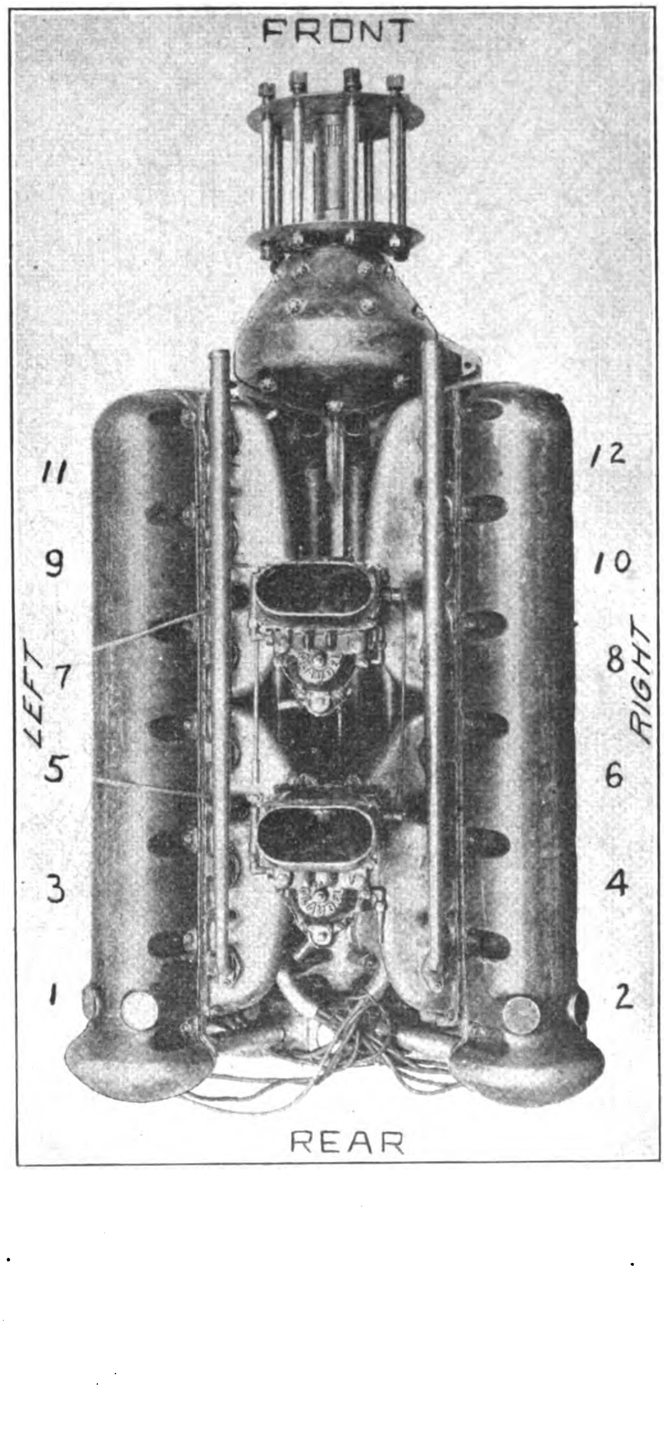


FIG. 3.—Plan view.

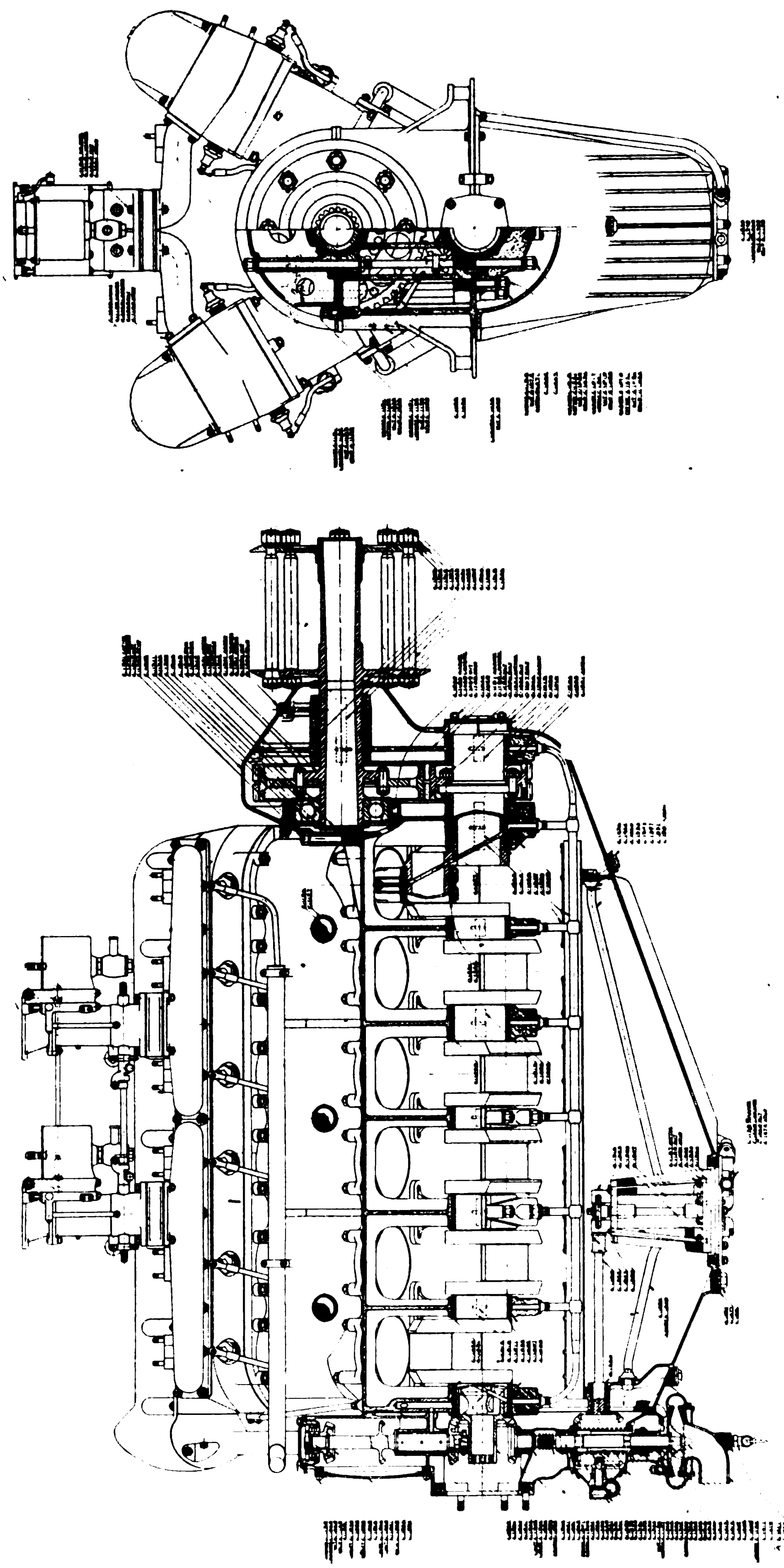


Fig. 4.—Longitudinal section and propeller end view

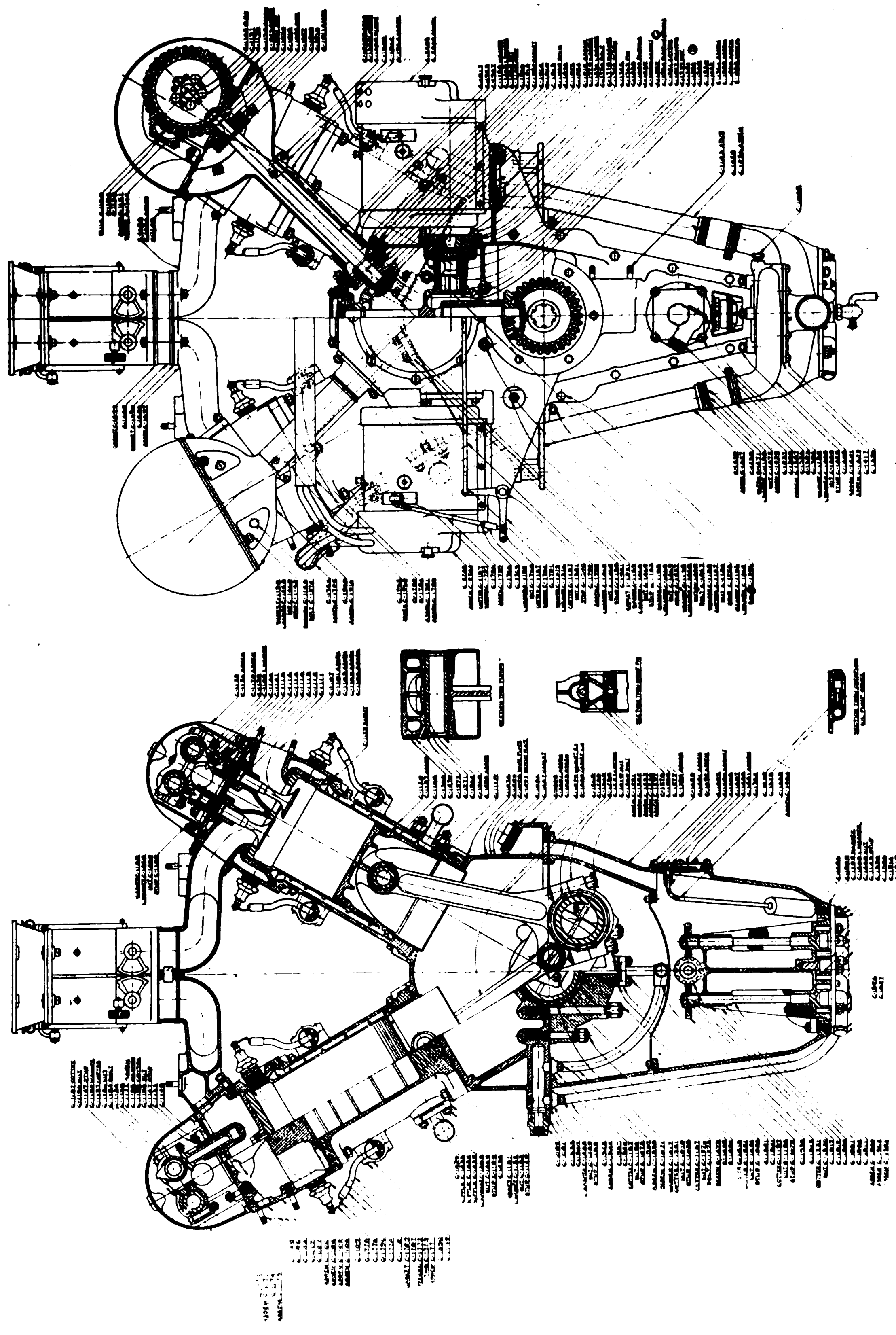


FIG. 5.—Transverse section and rear end view.

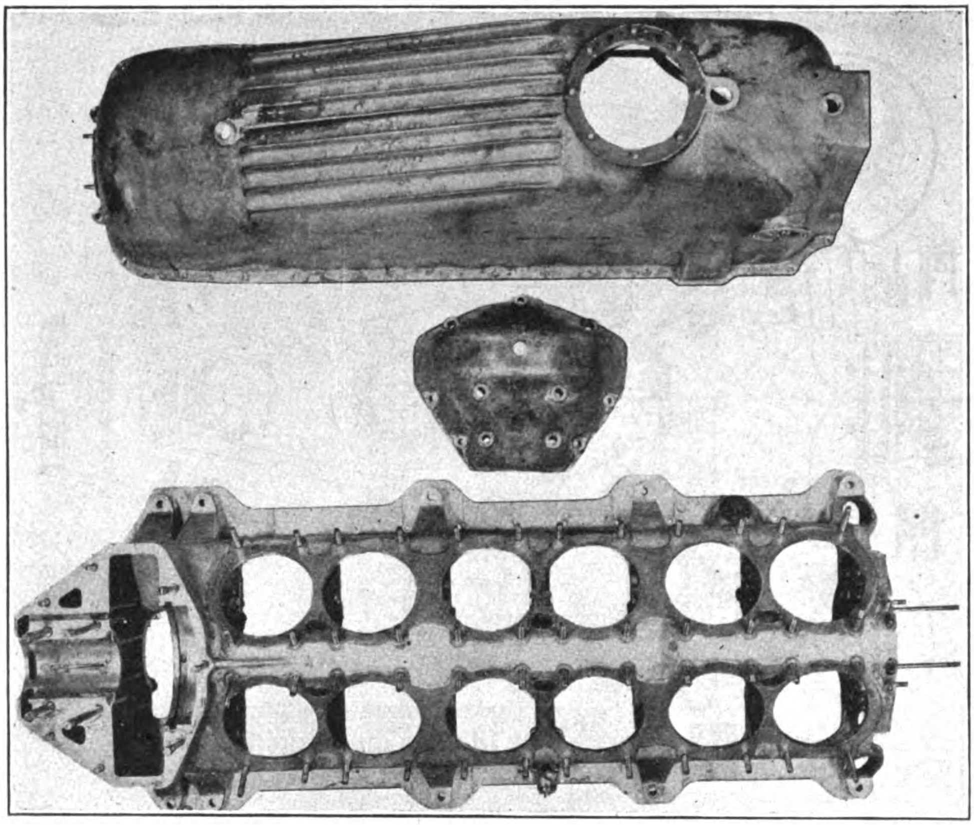


FIG. 6.—Crankcase, upper and lower halves, outside view.

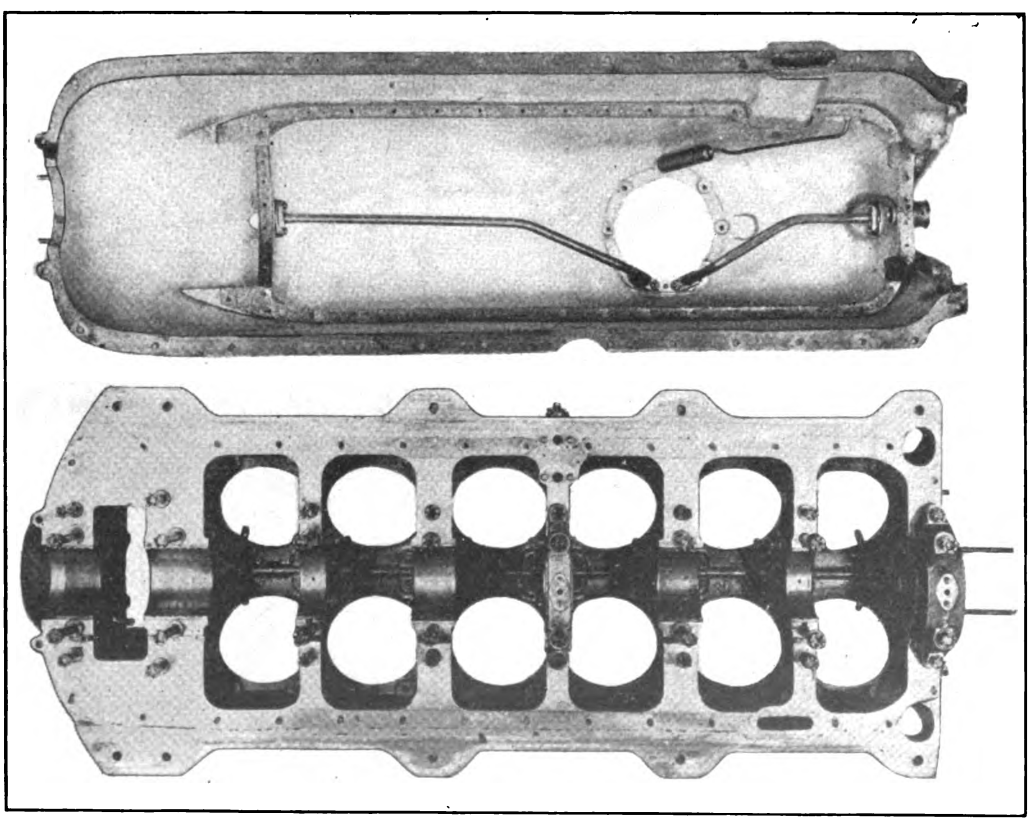


FIG. 7.—Crankcase ,upper and lower halves, inside view.

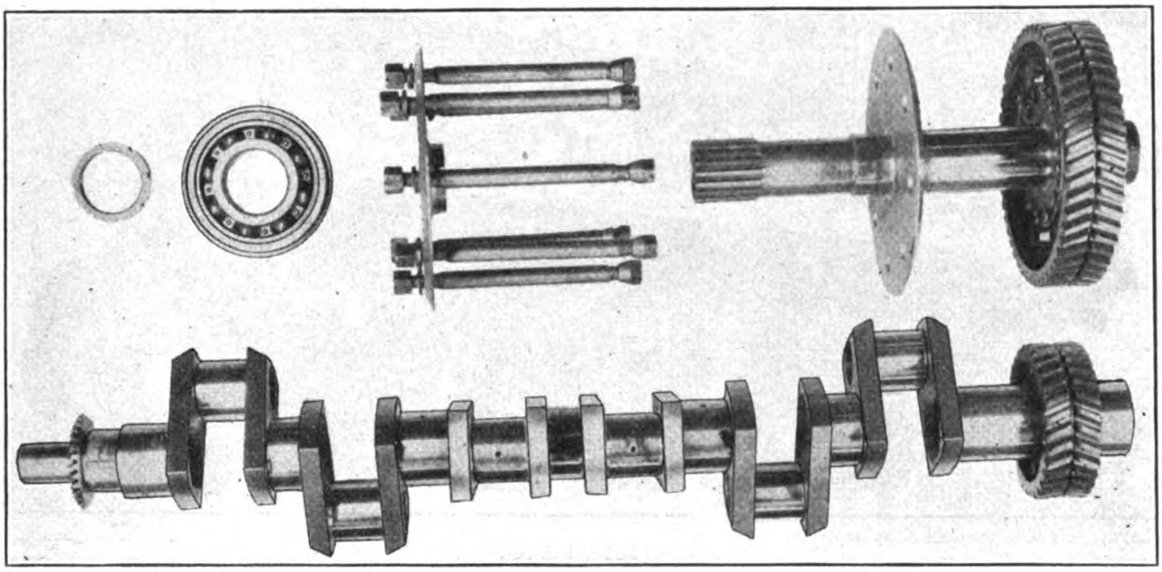


FIG. 8.—Crankshaft, reduction gear, propeller shaft, and propeller hub.

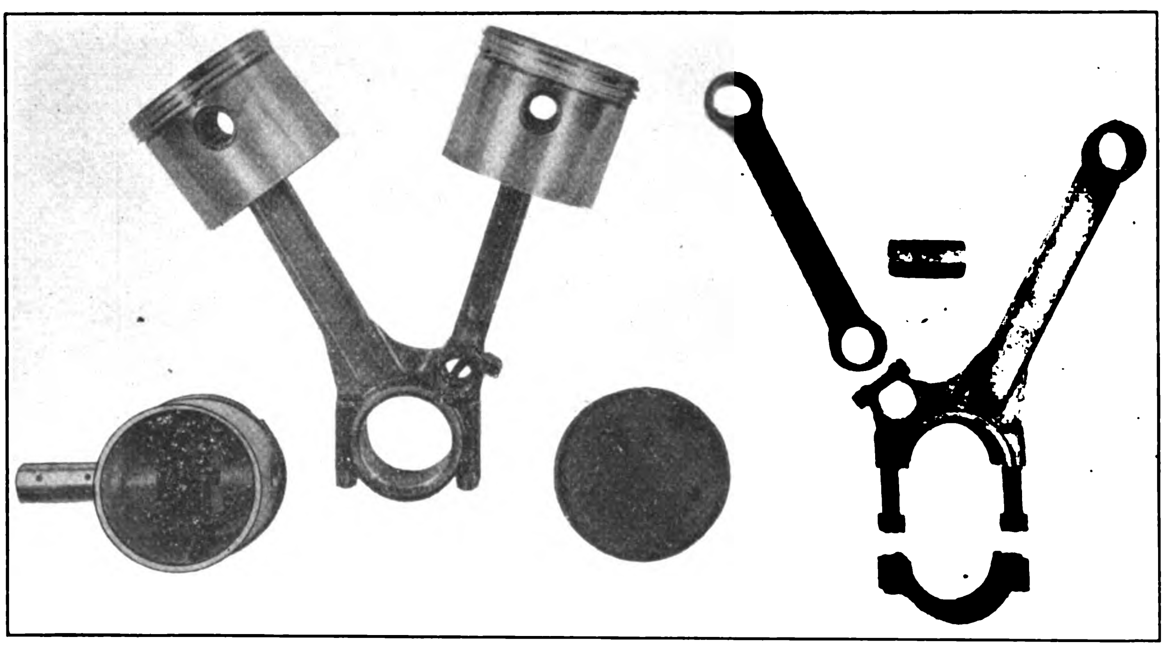


FIG. 9.—Pistons and connecting rods.

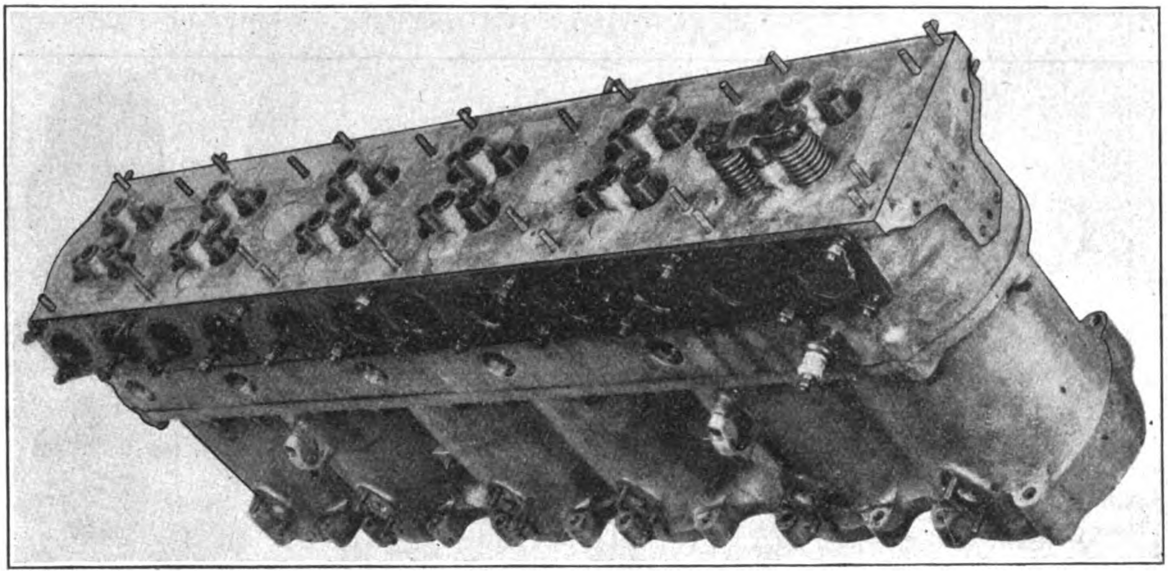


FIG. 10.—Cylinder block assembly.

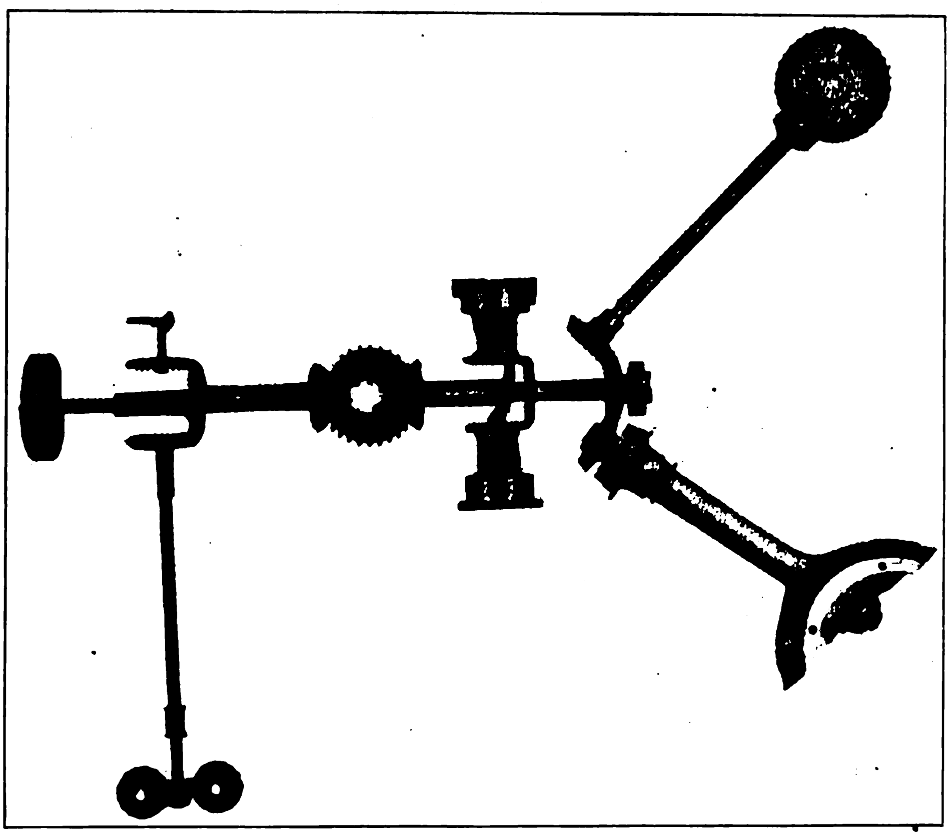


FIG. 11.—Drives laid out according to location of engine.

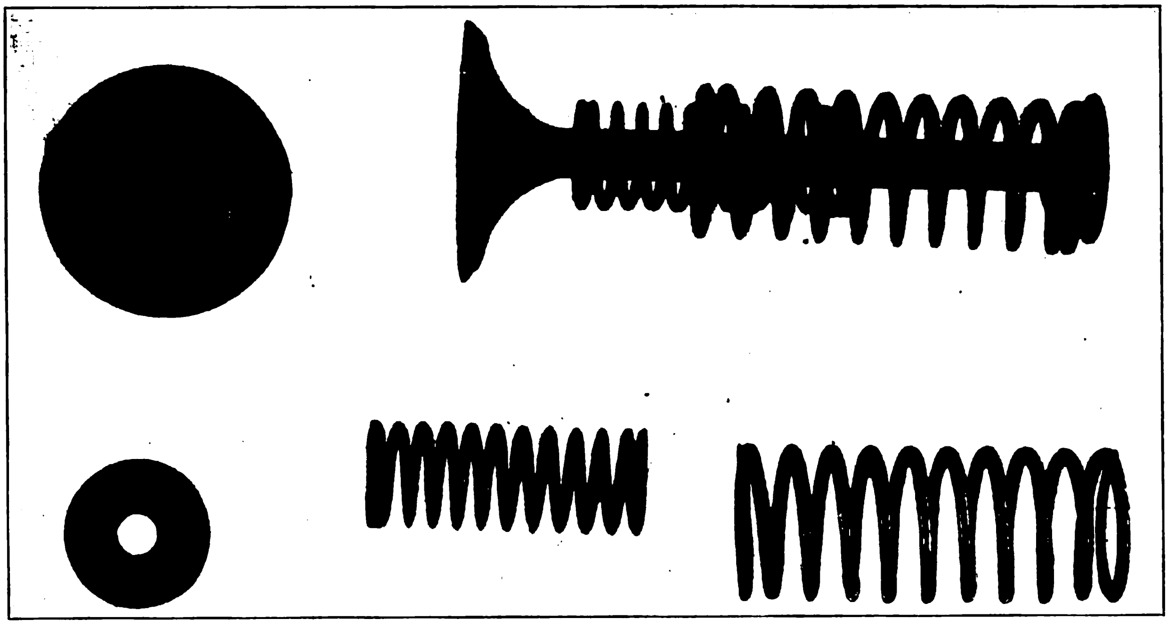


FIG. 12.—Valves and valve springs.

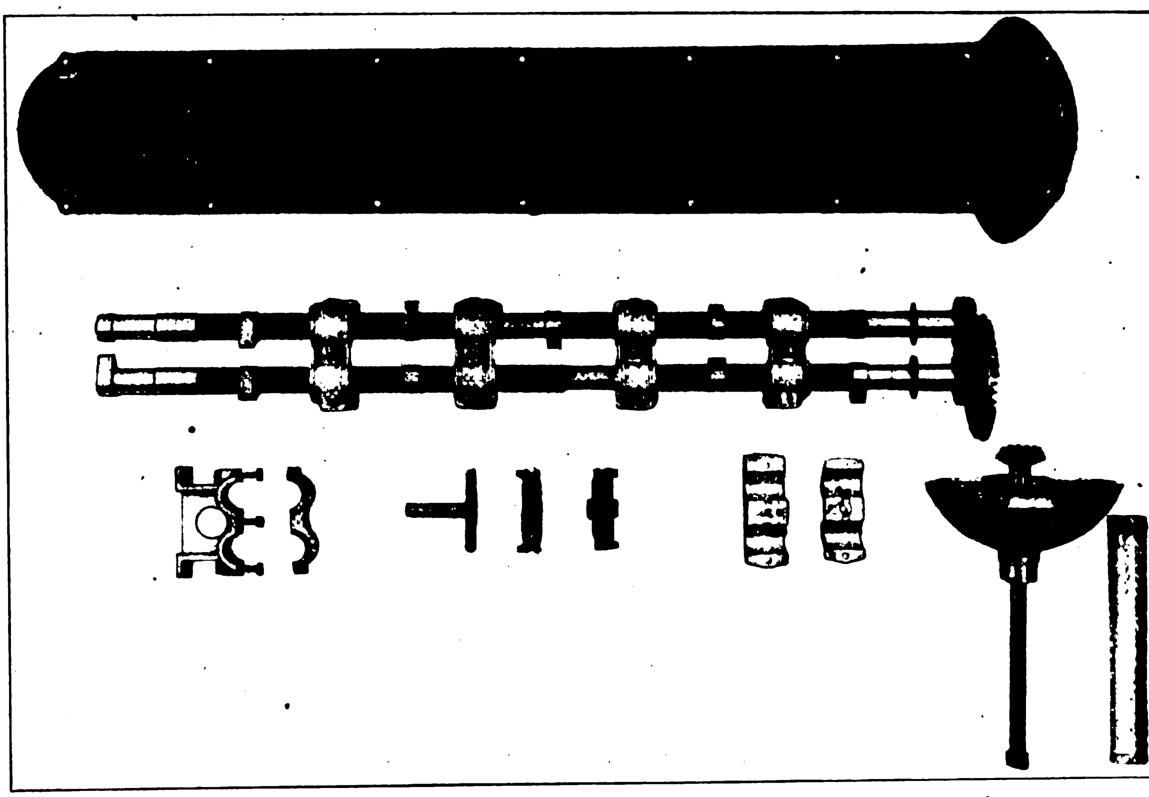


FIG. 13.—Valve gear.

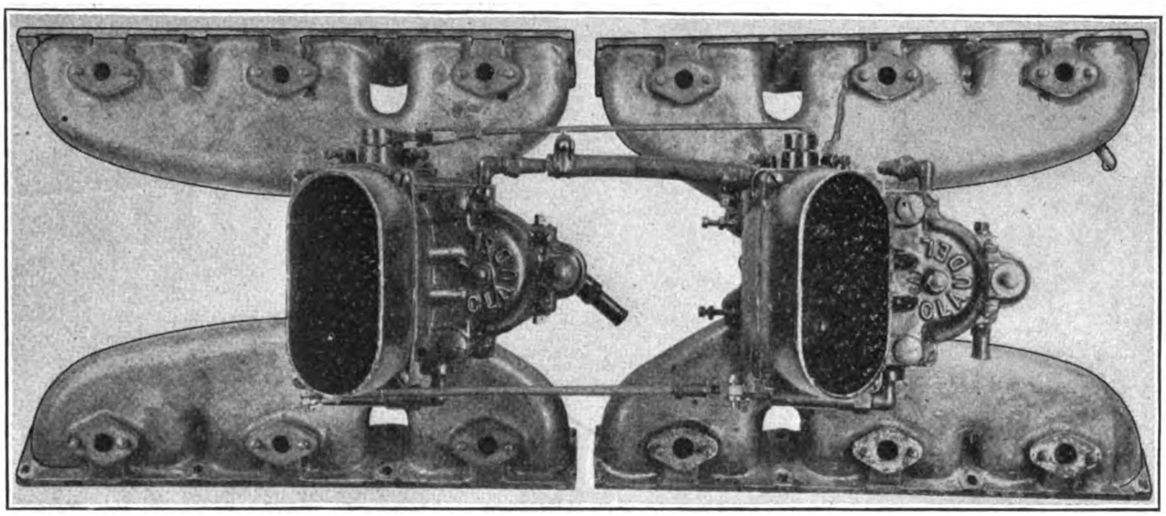


FIG. 14.—Carburetors and intake headers.

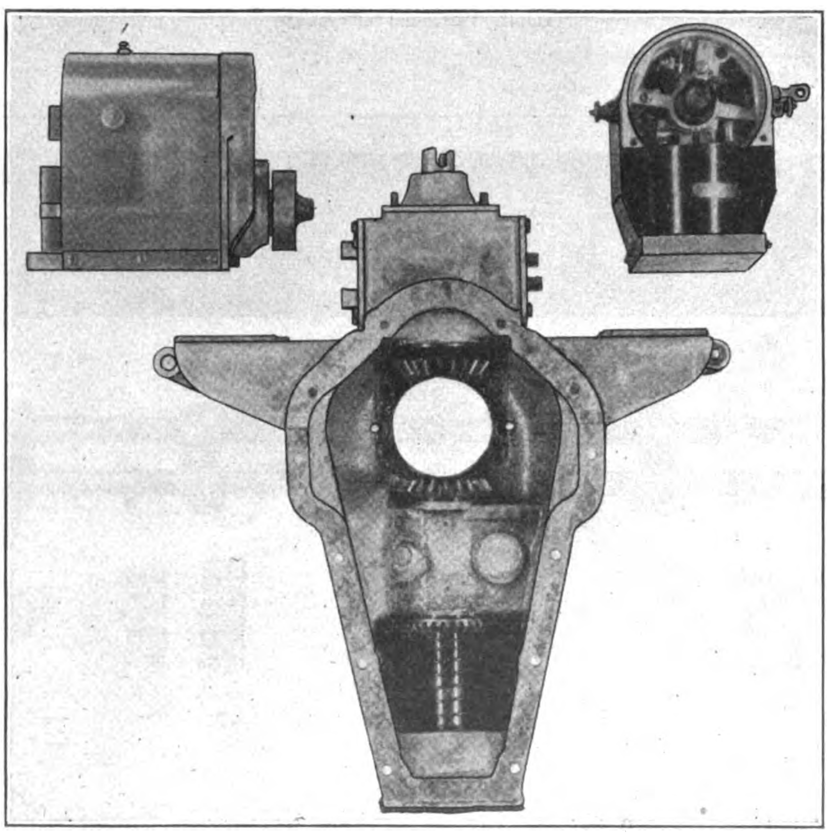


FIG. 15.—Drive gear train housing and magnetos.

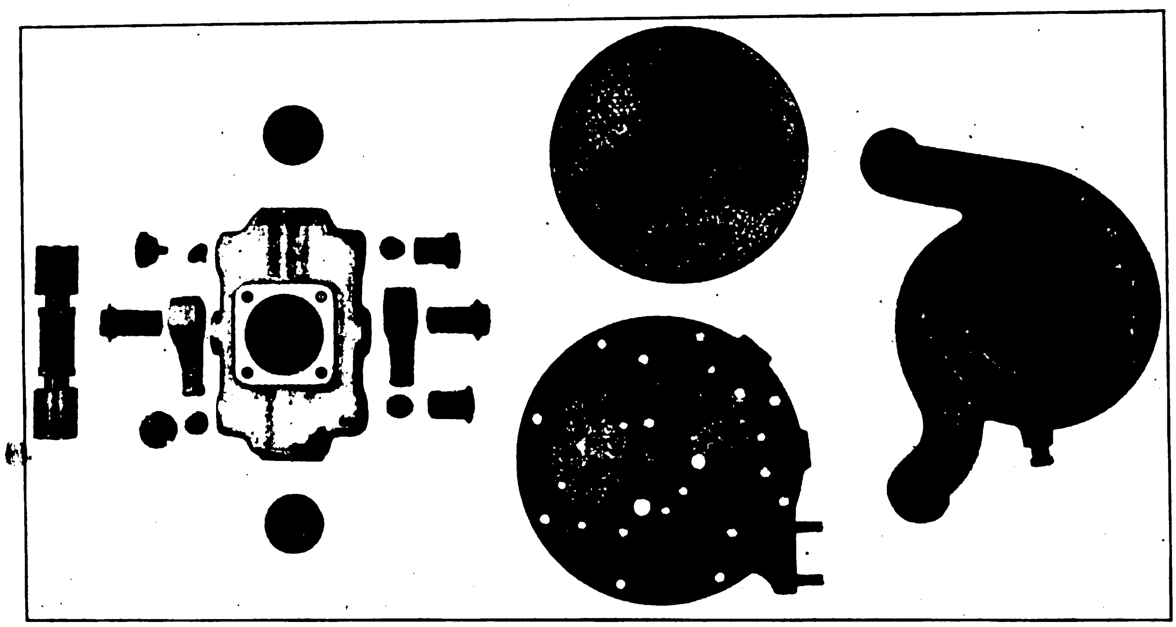


Fig. 16.—Oil pump, water pump, and gasoline pump.

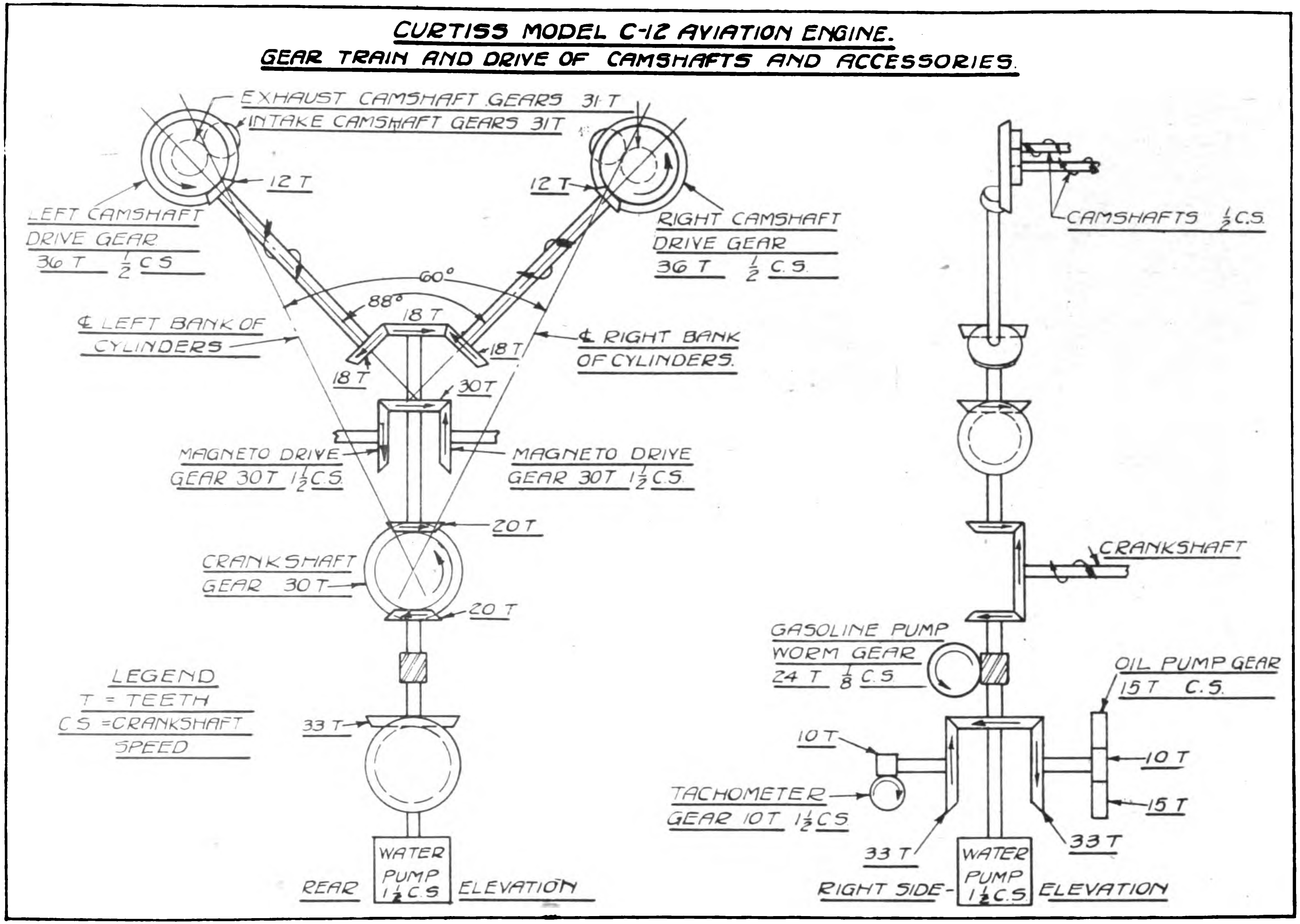

CURTISS MODEL C-12 AVIATION ENGINE.
GEAR TRAIN AND DRIVE OF CAMSHAFTS AND ACCESSORIES.
EXHAUST CAMSHAFT GEARS 31 T
INTAKE CAMSHAFT GEARS 31 T
12 T
12 T
LEFT CAMSHAFT DRIVE GEAR 36 T 1/2 C.S.
RIGHT CAMSHAFT DRIVE GEAR 36 T 1/2 C.S.
60°
88°
18 T
18 T
18 T
℄ LEFT BANK OF CYLINDERS
℄ RIGHT BANK OF CYLINDERS
30 T
MAGNETO DRIVE GEAR 30 T 1 1/2 C.S.
MAGNETO DRIVE GEAR 30 T 1 1/2 C.S.
20 T
CRANKSHAFT GEAR 30 T
20 T
LEGEND
T = TEETH
C.S. = CRANKSHAFT SPEED
33 T
WATER PUMP 1 1/2 C.S.
REAR ELEVATION
CAMSHAFTS 1/2 C.S.
CRANKSHAFT
GASOLINE PUMP WORM GEAR 24 T 1/8 C.S.
OIL PUMP GEAR 15 T C.S.
10 T
10 T
15 T
TACHOMETER GEAR 10 T 1 1/2 C.S.
33 T
33 T
WATER PUMP 1 1/2 C.S.
RIGHT SIDE-ELEVATION

FIG. 17.

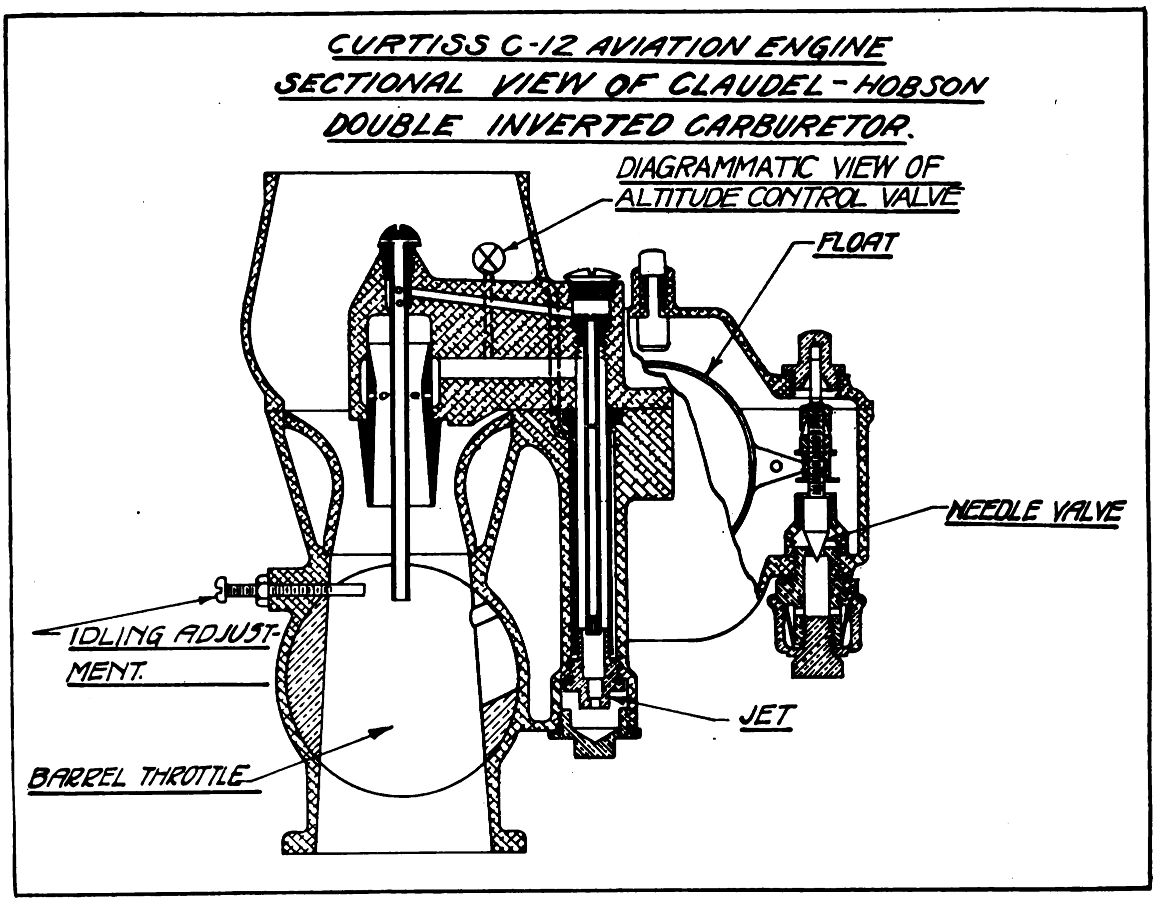

CURTISS C-12 AVIATION ENGINE
SECTIONAL VIEW OF CLAUDEL-HOBSON
DOUBLE INVERTED CARBURETOR.
DIAGRAMMATIC VIEW OF ALTITUDE CONTROL VALVE
FLOAT
NEEDLE VALVE
IDLING ADJUSTMENT.
JET
BARREL THROTTLE

FIG. 18.

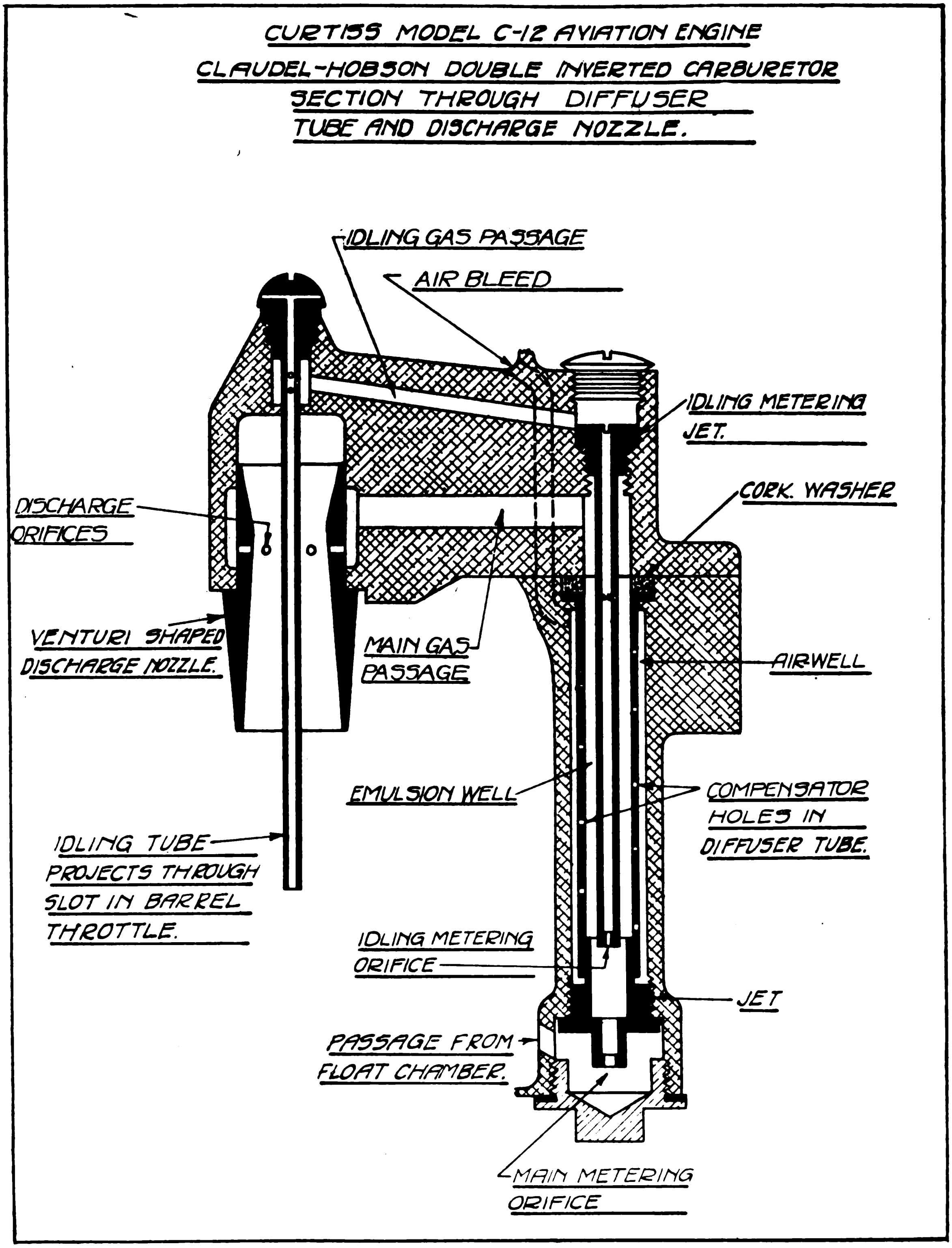

CURTISS MODEL C-12 AVIATION ENGINE
CLAUDEL-HOBSON DOUBLE INVERTED CARBURETOR
SECTION THROUGH DIFFUSER
TUBE AND DISCHARGE NOZZLE.
IDLING GAS PASSAGE
AIR BLEED
IDLING METERING JET.
CORK. WASHER
DISCHARGE ORIFICES
VENTURI SHAPED DISCHARGE NOZZLE.
MAIN GAS PASSAGE
AIRWELL
EMULSION WELL
COMPENSATOR HOLES IN DIFFUSER TUBE.
IDLING TUBE PROJECTS THROUGH SLOT IN BARREL THROTTLE.
IDLING METERING ORIFICE
JET
PASSAGE FROM FLOAT CHAMBER.
MAIN METERING ORIFICE

FIG. 19

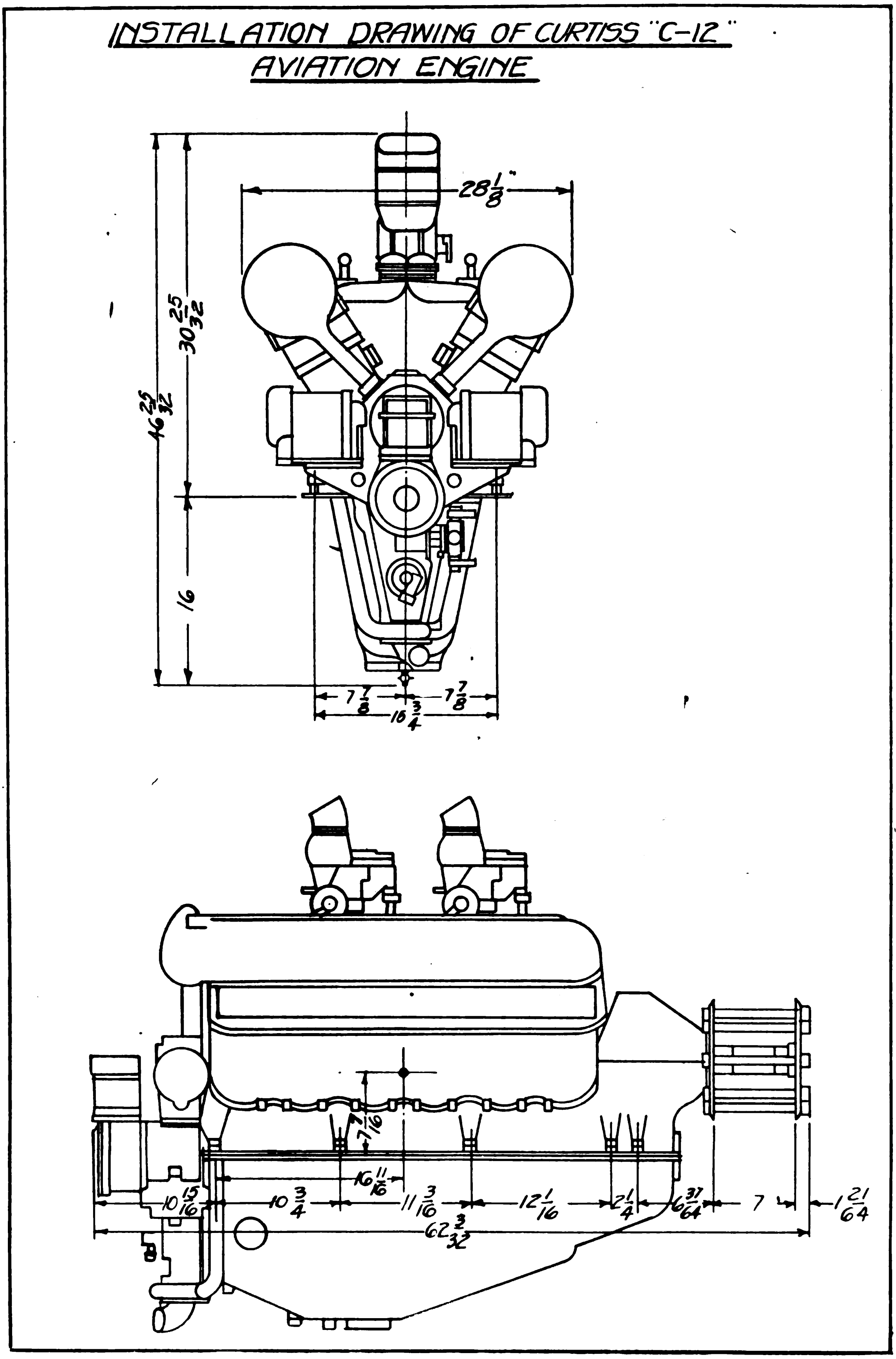

INSTALLATION DRAWING OF CURTISS "C-12"
AVIATION ENGINE
28 1/8"
30 25/32
46 25/32
16
7 7/8
7 7/8
16 3/4
7 1/16
16 11/16
10 15/16
10 3/4
11 3/16
12 1/16
2 1/4
6 37/64
7
1 21/64
62 3/32

Fig. 20.

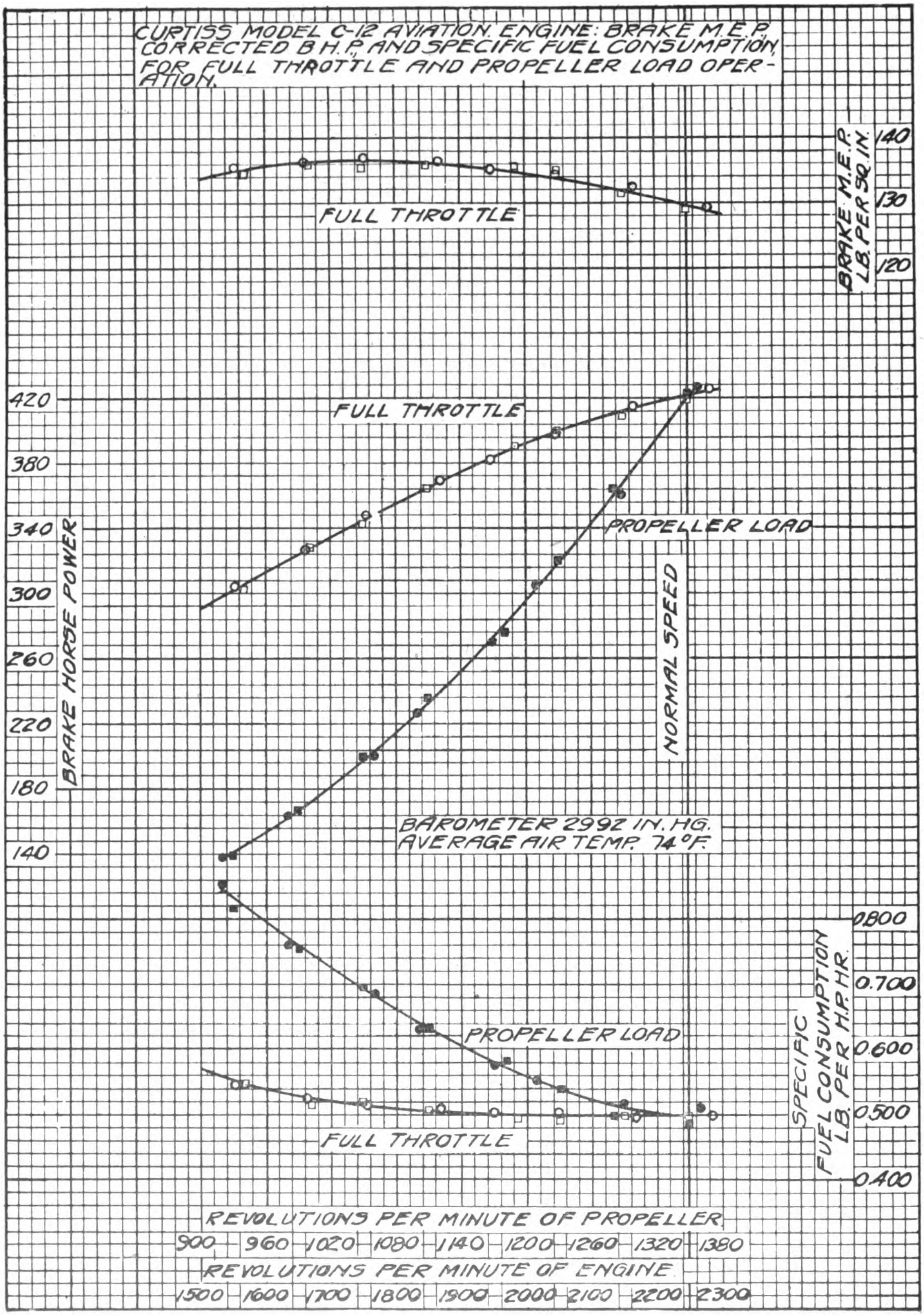

CURTISS MODEL C-12 AVIATION ENGINE: BRAKE M.E.P. CORRECTED B.H.P. AND SPECIFIC FUEL CONSUMPTION FOR FULL THROTTLE AND PROPELLER LOAD OPERATION.
BRAKE M.E.P. LB. PER SQ. IN.
140
130
120
FULL THROTTLE
420
380
340
300
260
220
180
140
BRAKE HORSE POWER
FULL THROTTLE
PROPELLER LOAD
NORMAL SPEED
BAROMETER 29.92 IN. HG.
AVERAGE AIR TEMP. 74°F.
PROPELLER LOAD
FULL THROTTLE
SPECIFIC FUEL CONSUMPTION LB. PER H.P. HR.
0.800
0.700
0.600
0.500
0.400
REVOLUTIONS PER MINUTE OF PROPELLER
900
960
1020
1080
1140
1200
1260
1320
1380
REVOLUTIONS PER MINUTE OF ENGINE
1500
1600
1700
1800
1900
2000
2100
2200
2300

FIG. 21.

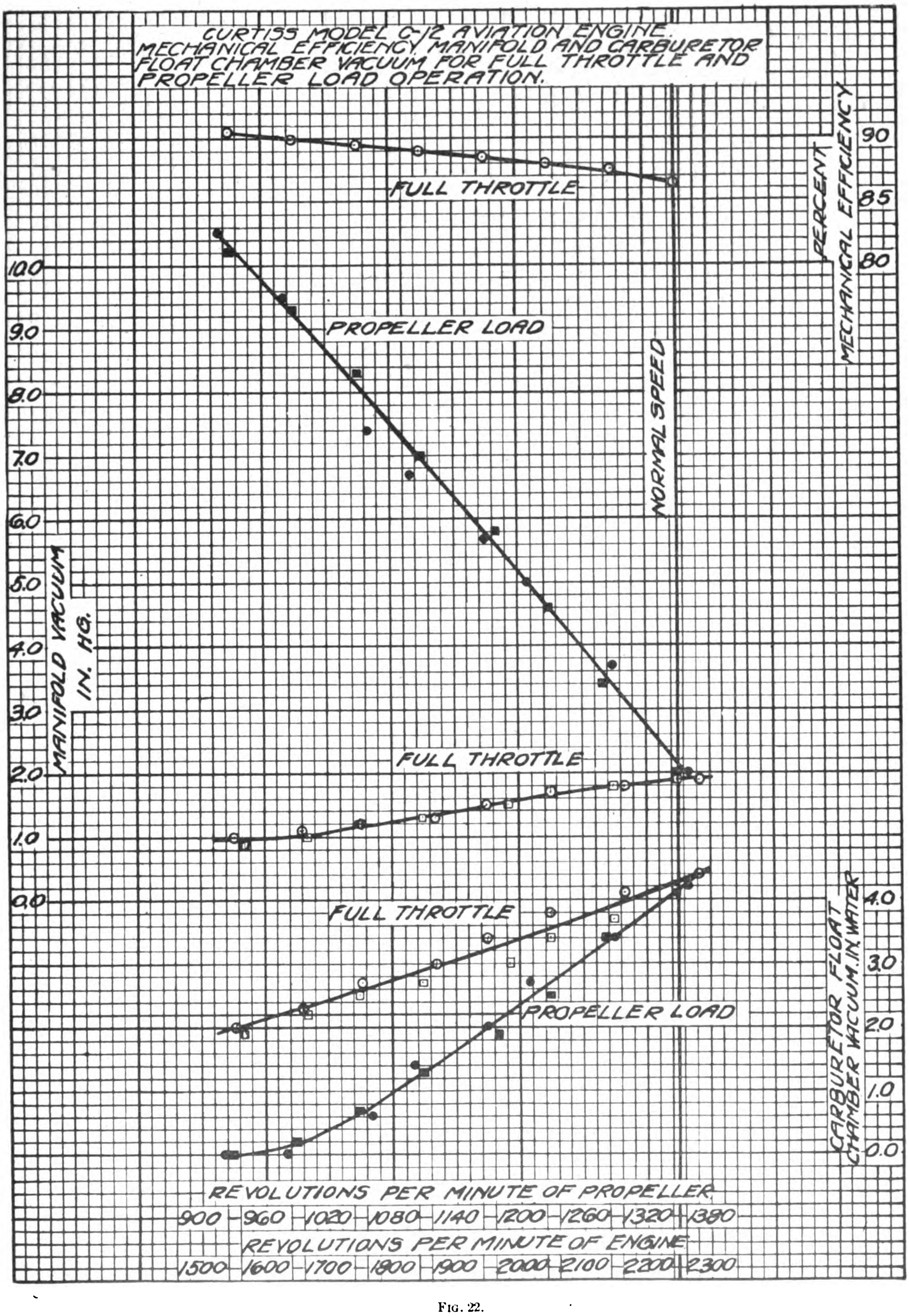

CURTISS MODEL C-12 AVIATION ENGINE.
MECHANICAL EFFICIENCY MANIFOLD AND CARBURETOR FLOAT CHAMBER VACUUM FOR FULL THROTTLE AND PROPELLER LOAD OPERATION.
FULL THROTTLE
PROPELLER LOAD
NORMAL SPEED
PERCENT MECHANICAL EFFICIENCY
90
85
80
MANIFOLD VACUUM IN. HG.
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
FULL THROTTLE
FULL THROTTLE
PROPELLER LOAD
CARBURETOR FLOAT CHAMBER VACUUM, IN. WATER
4.0
3.0
2.0
1.0
0.0
REVOLUTIONS PER MINUTE OF PROPELLER
900 960 1020 1080 1140 1200 1260 1320 1380
REVOLUTIONS PER MINUTE OF ENGINE
1500 1600 1700 1800 1900 2000 2100 2200 2300

Fig. 22.

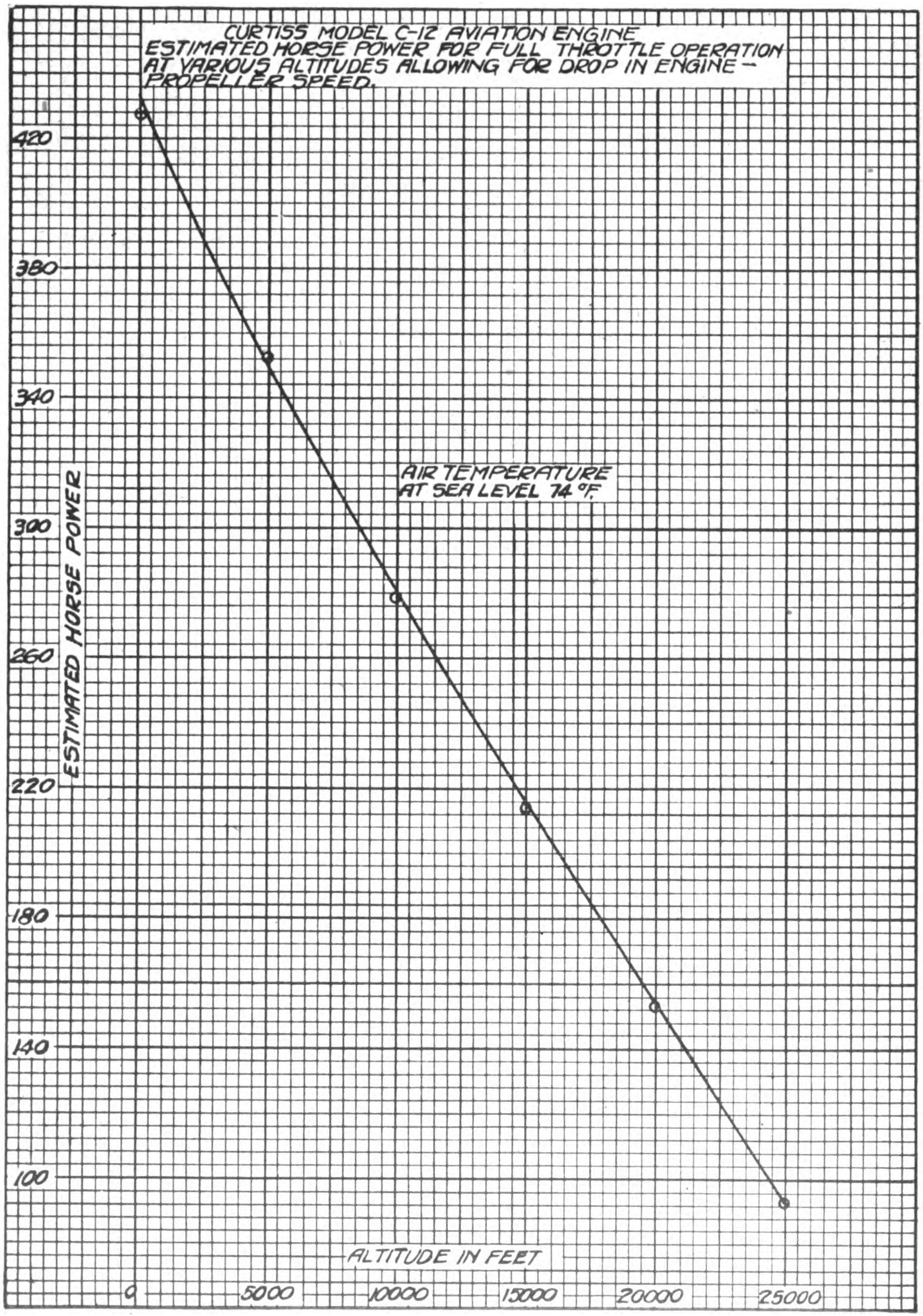

CURTISS MODEL C-12 AVIATION ENGINE
ESTIMATED HORSE POWER FOR FULL THROTTLE OPERATION
AT VARIOUS ALTITUDES ALLOWING FOR DROP IN ENGINE—
PROPELLER SPEED.
AIR TEMPERATURE
AT SEA LEVEL 74 °F.
ESTIMATED HORSE POWER
420
380
340
300
260
220
180
140
100
ALTITUDE IN FEET
0
5000
10000
15000
20000
25000

FIG. 23.

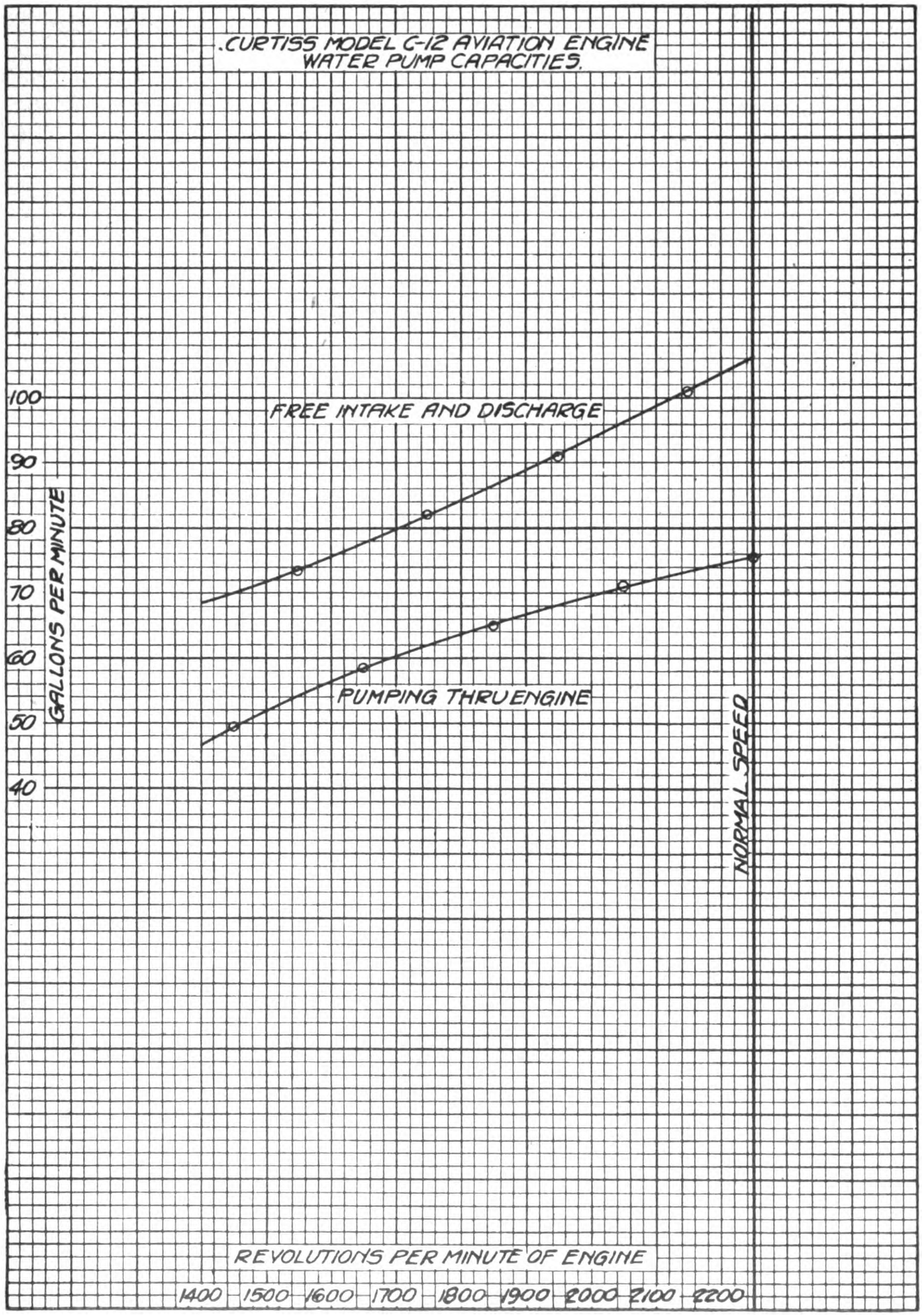

CURTISS MODEL C-12 AVIATION ENGINE
WATER PUMP CAPACITIES.
FREE INTAKE AND DISCHARGE
PUMPING THRU ENGINE
NORMAL SPEED
GALLONS PER MINUTE
100
90
80
70
60
50
40
REVOLUTIONS PER MINUTE OF ENGINE
1400
1500
1600
1700
1800
1900
2000
2100
2200

Fig. 24.

File D 52.1 / J. L. 6 / 7 *McCOOK FIELD REPORT, SERIAL No. 1795*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV March 15, 1922 No. 332

STUDY OF STRESS ANALYSIS OF THE JL-6

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
November 15, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

STUDY OF STRESS ANALYSIS OF THE JL-6.

INTRODUCTION.

The airplane known in America as the JL-6 is the T-13 of Prof. Hugo Junker. The airplane is constructed entirely of metal, chiefly duralumin, and contains several unique structural features. The most important features are the multispar wing bracing and the monocoque type of fuselage. Both of these types of construction are extremely difficult to design rationally, as they are very indeterminate statically. Fortunately, the Air Service has been able to obtain through Mr. A. Klemin blue prints of some of the stress analysis used in the design of this airplane. This data has been carefully gone over to learn as much as possible of the methods used by Prof. Junker in making his design.

CHASSIS.

The data on the chassis is meager. Results of tests on individual chassis struts are given and the ultimate strength of the chassis stated, but the connecting links in the analysis are missing. The type of chassis used, however, is not at all difficult to design. It is of interest to note that the resilience of the chassis is translated into height of drop which the chassis can sustain. This drop is 0.5 meter, or about 20 inches.

FUSELAGE.

Apparently a static test was made of a smaller but similar fuselage for the T-10 and the assumptions made that the strength of the T-10 and T-13 fuselages was in proportion to the ratios of the heights and breadths of the two designs. This would probably be the case if the larger fuselage were not more subject to local crinkling failure. The actual failing load of the JL-6 as found in static test at McCook Field was about 80 per cent of that predicted by the designer.

A computation of the strength of a fuselage bulkhead was given but no connection with probable loads is shown. Also a diagram is shown to indicate the strength of the fuselage in case of accident resulting in the airplane landing upside down. No information of value for purposes of stress analysis was drawn from either of them.

EMPENNAGE.

The data on the empennage is insufficient to give a clear idea of the methods used in its design. The designer takes into account the fact that at some angles of attack the loads on the stabilizer and elevator are in different directions. Some stress diagrams were shown, but no information of value was obtained from them.

WINGS.

The most interesting information obtained from the data on hand was in respect to the method of designing the wings. While the available information was insufficient to make it possible to state definitely the methods used in its design, enough was given for one to learn the general outline of the method. One of the chief difficulties in interpreting the computations was the fact that it was not found possible to get an exact check on the figures in those cases where a step was left out. It is believed, however, that the procedure used was, in general, that described below.

The net load on the wing was computed, making an allowance for wing tip loss, and moment and shear curves were drawn for the wing as a whole. This was done for two cases. In Case I the load per square foot was assumed constant over the entire wing except for the wing tip loss. In Case II the load per square foot was assumed constant over a reduced wing. This reduced wing had the same chord at the center as the actual wing but only two-thirds the chord of the actual wing at the tip. As Case I was more severe than Case II the design was made for that condition of loading.

As the spar tubes are very rigidly connected by the web diagonals the whole wing was assumed to act as a unit and the location of the center of pressure neglected. The unit stress in each tube was obtained from the formula $f=My/I$ where y is the distance from the neutral axis to the tube in question, and I the moment of inertia of the tubes about the neutral axis. The tube size was chosen so that I would be large enough to make f a reasonable value in the most stressed tube. Apparently, 50 × 2 mm. tubes were first chosen and the gauge reduced later to 1.5 mm. To find the stresses in the diagonal members, the vertical projection of the deepest of the trusses was drawn up and the entire load on the wing divided into panel loads on this truss. The stresses in this truss were then computed under the loads shown. Having found what the stresses in this truss would be if it carried the entire load it was desired to compute the proportion of the entire load actually carried by it. This was done from the formula

$$S=\frac{100\ M_b\, e\, g}{I\ P}$$

M_b is the moment on the wing at some section b, I the moment of inertia of the tubes at that section, and e the distance from the neutral axis of the most stressed tube. $M_b\, e/I$ is therefore the intensity of stress in that tube. Section b is taken in this case where the wing is attached to the fuselage. Multiplying $M_b\, e/I$ by g, half the cross sectional area of the tube gives the actual load in one chord of the truss. One-half the area of the tube is used as each

tube is a chord member of two trusses. P is the load in the chord member if the entire load is carried by the one truss. S, therefore, is the per cent of the total load carried by the one truss. In the JL-6 the load carried by the worst stressed truss is computed as 25.6 per cent of the total. The stresses in the members of the deepest truss under the entire load are multiplied by 0.256 to find the actual loads. The loads in the chord members are multiplied by 2.0 as each tube is a member of two trusses, while the loads in the web members are corrected to allow for the difference in slope between the actual member and its vertical projection. The factors of safety are then computed for the members of the deepest truss. The shallower trusses are assumed to be relatively stronger than the deepest one and the stresses were not computed.

The minimum factor of safety, according to the computations, is 4.6 and is at a section about midway between the wing tip and the connection between the wing section and the fuselage section. The actual failure in static test, however, was a tension failure at the joint between wing section and fuselage section, and occurred under a load of 6.5. The wings safely supported a load of 6.0. This shows that the method of design is approximate and not precise, but that it is conservative.

The wing structure obtained is heavier than would have been a wooden structure of the Fokker monoplane type. The Fokker has a slightly heavier wing loading which is in its favor, but a greater effective aspect ratio and a higher strength factor, both of which are in favor of the Junker, yet the Fokker wings weigh only 1.565 pounds per square foot to 1.546 for the JL-6. On the other hand, the Junker construction is much stiffer than the Fokker.

In computing the moment of inertia of the group of tubes little error will be made if the horizontal line through the center of gravity be assumed the neutral axis. In the JL-6 the angle between this line and the true neutral axis is nery small.

STRENGTH OF DURALUMIN.

With the data on the JL-6 was a chart giving the results of compression tests on a series of duralumin tubes. These tubes ranged in size from about 2 inches diameter 0.060 gauge to 0.6 inch diameter 0.020 gauge. The test results are plotted with values of the failing load in kilograms per square millimeter as ordinates and ratios of length to diameters as abscissas. The tubes were tested as pin ended struts. In addition to the test results a mean curve is plotted for use in design. This mean curve is made up of a straight line for short struts and Euler's curve for long ones. Translating the units from the metric to the English system the equations of the mean curve are as follows:

Straight line:

$P/A = 57{,}000 - 1{,}492\ L/d$ (d is the diameter of the tube).

Euler:

$P/A = \frac{\pi^2 E}{8(L/d)^2}$ with $E = 10{,}700{,}000$ pounds per square inch.

The above expressions are those used in the test, the actual curves plotted are a little below those values.

The curve plotted from the equation $P/A = 47{,}000 - 400\ L/\rho$ and $P/A = \frac{\pi^2 E}{(L/\rho)^2}$ with $E = 9{,}725{,}000$ pounds per square inch, which has been tentatively adopted by the Air Service, agrees very well with the weaker test results obtained by Junker, and represents the average minimum rather than the average strength of the tubing given by Junker's curves.

File D 52.338/33 *McCOOK FIELD REPORT SERIAL No. 1789*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | March 15, 1922 | No. 334

REPORT ON WIND TUNNEL TEST OF U.S.A-27-C MODIFIED AIRFOIL

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
December 5, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT ON WIND TUNNEL TEST OF U. S. A.-27-C MODIFIED AIRFOIL.

OBJECT OF TEST AND DESCRIPTION OF THE MODEL.

This airfoil was tested at M. I. T. during September, 1921, to determine lift, drag, L/D, and moments about the leading edge. The test was run at a wind velocity of 30 miles per hour. The area of the model is 68 square inches, and is tapered both in chord and section except for a constant center section extending over 23.4 per cent of the span. The dimensions are: Span 18 inches; chord at center line 4.368 inches.

RESULTS.

The results of the test on this airfoil are compared with results of tests on the original U. S. A.-27-C, the U. S. A.-27, and the Dayton-Wright Gottingen No. 387.

It should be noted in the results on the modified U. S. A.-27-C that the angle of attack is referred to the flat portion of the chord near the trailing edge, and not to the line connecting the leading and trailing edges. This accounts for the rather abnormal angle of zero lift.

The maximum lift coefficient for the modified U. S. A.-27-C is 0.00366 as compared to 0.00332 for the U. S. A.-27-C, 0.00363 for the U. S. A.-27, and 0.00415 for the Dayton-Wright Gottingen No. 387. The minimum drag coefficient is 0.000062, and the ratio of the maximum lift to minimum drag is therefore 59.0. This ratio for the U. S. A.-27-C is 55.3, for the U. S. A.-27 is 45.4, and for the D. W. Gottingen No. 387 it is 42.4. The maximum L/D ratio is 14.1, as compared to 15.2 for the U. S. A.-27-C, 16.0 for the U. S. A.-27, and 13.5 for the D. W. Gottingen No. 387.

The high speed for pursuit airplanes is compared by the L/D taken at 1/9 maximum Ky. The L/D for the modified model of the U. S. A.-27-C at this Ky is 5.65, as compared to 6.1 for the U. S. A.-27-C, 4.6 for the U. S. A.-27, and 4.5 for the D. W. Gottingen No. 387. The high speed for reconnaissance airplanes is compared by the L/D taken at 1/6.25 of the maximum Ky. At this Ky the L/D for the modified U. S. A.-27-C is 8.7, as compared to 8.8 for the U. S. A.-27-C, 7.0 for the U. S. A.-27, and 6.75 for the D. W. Gottingen No. 387. The high speed for bombers is taken at the angle corresponding to 1/4 maximum Ky. At this angle the L/D for the modified U. S. A.-27-C is 12.4, while that for the U. S. A-27-C is 12.6, 11.7 for the U. S. A.-27, and 10.45 for the D. W. Gottingen No. 387.

A comparable value for the speed range is obtained by means of the formula

$$\frac{\sqrt{\text{Ky maximum}}}{\sqrt[3]{\text{Kx minimum}}}$$

The value for the modified U. S. A.-27-C is 1.525, for the U. S. A.-27-C it is 1.478, and for both the U. S. A.-27 and the D. W. Gottingen No. 387 it is 1.410.

The ceiling and climb for constant loading is expressed by the maximum value of the formula $Ky^{3/2}/Kx$. The maximum value of this expression for the modified U. S. A.-27-C is 0.578, 0.650 for the U. S. A.-27-C, 0.665 for the U. S. A.-27, and 0.623 for the D. W. Gottingen No. 387. The ceiling and climb for constant landing speed is expressed by the minimum value of the formula

$$\sqrt{\frac{\text{Ky maximum}}{\text{Ky}}} \over \text{L/D}.$$

For the modified U. S. A.-27-C the minimum value of the above expression is 0.1046, for the U. S. A.-27-C it is 0.0885, for the U. S. A.-27 it is 0.0908, and for the D. W. Gottingent No. 387 it is 0.1035.

The most forward position of the center of pressure is 33.8 per cent of the chord back of the leading edge for the modified U. S. A.-27-C, 29.6 per cent for the U. S. A.-27-C, 27.4 per cent for the U. S. A.-27, and 32.0 per cent for the D. W. Gottingen No. 387.

The center of pressure travel in per cent of the chord between the most forward position and the position at the angle of $\frac{\text{Ky maximum}}{6.25}$ for the modified U. S. A.-27-C is 31.0 per cent, for the U. S. A.-27-C it is 32.2 per cent, for the U. S. A.-27 it is 39.6 per cent, and for the D. W. Gottingen No. 387 it is 41.0 per cent.

The modified U. S. A.-27-C is of the thick-wing type section, having sufficient depth for internally braced construction. The spar depths for the various airfoils discussed in this report are given in Table I.

Table II and figures 1 and 2 give the characteristics of the airfoil. Table III is a table of ordinates expressed in per cent of chord. Figure 3 is a three-view drawing of the model.

It is noted that the ratio of the maximum lift to the minimum drag for the modified U. S. A.-27-C is 59.0 per cent, this value being a remarkably high one and higher than the corresponding values for the other sections discussed. The maximum lift coefficient is excellent, it being less than the D. W. Gottingen No. 387, slightly better than the U. S. A.-27, and considerably superior to the U. S. A.-27-C. The maximum L/D ratio is 14.1 per cent, which is less than either the U. S. A.-27 or the U. S. A.-27-C, but greater than the value for the D. W. Gottingen No. 387, which is 13.5 per cent. A comparison of the L/D ratio for high speeds of various types of airplanes show the values for the modified U. S. A.-27-C to be slightly less than the U. S. A.-27-C and considerably superior to either the U. S. A.-27 or the D. W. Gottingen No. 387.

The speed range for the modified U. S. A.-27-C is exceptionally high, being 1.525, which is greater than the value for any of the other sections discussed. On the other hand, the values for ceiling and climb for both constant loading and constant landing speed are very poor, the value for constant loading being 0.578, which is considerably less than the minimum value for any of the other sections, and for constant landing speed the value is 0.1046, which is much higher than the value for any of the other sections. In this latter case the minimum value is the criterion of merit.

The most forward position of the center of pressure for the modified U. S. A.–27–C is 33.8 per cent, while the center of travel is 31.0 per cent of the chord. The most forward position of the center of pressure is a little farther back on the chord than any of the other sections, while the center of pressure travel is not so great as any of the others.

TABLE I.—*Comparison of airfoils.*

Airfoil.	Dayton-Wright Gottingen 387.	U. S. A.-27.	U. S. A.-27-C.	U. S. A.-27-C (modified).
Ky maximum (landing)	0.00415	0.00363	0.00332	0.00366
Kx minimum	.000098	.00008	.00006	.000062
Ky maximum/Kx minimum	42.4	45.4	55.3	59.0
L/D maximum (cruising)	13.5	16.1	15.2	14.1
High-speed pursuit, L/D at 1/9 Ky maximum	4.5	4.6	6.1	5.65
High-speed reconnaissance, L/D at 1/6/25 Ky maximum	6.75	7.0	8.8	8.7
High-speed bomber, L/D at 1/4 Ky maximum	10.45	11.7	12.6	12.4
Speed range $\frac{\sqrt{Ky \text{ maximum}}}{\sqrt{Kx \text{ minimum}}}$	1.410	1.410	1.478	1.525
Ceiling and climb for constant loading $Ky^{3/2}/Kx$ maximum	.623	.665	.650	.578
Ceiling and climb for constant landing speed $\sqrt{\frac{Ky \text{ max.}}{\frac{Ky}{L/D}}}$ min.	.1035	.0908	.0885	.1046
Most forward position of center of pressure	32.0	27.4	29.6	33.8
Center of pressure travel in per cent of chord between most forward position and position at angle of Ky max./6.25	41.0	39.6	32.2	31.0
Spar depths:				
10 per cent from leading edge	12.07	9.17	13.23	13.23
15 per cent from leading edge	13.83	10.40	....	....
60 per cent from leading edge	11.05	9.27	13.33	13.33
70 per cent from leading edge	8.62	7.90	11.00	11.00
Authority	M. I. T.	M. I. T.	M. I. T.	M. I. T.
Velocity (miles per hour)	30	30	30	30
Aspect ratio	....	6	6	....

TABLE II.

Authority, Aerodynamical Laboratory, M. I. T., September, 1921; velocity, 30 miles per hour; model, 18 by 4.368 inches at centerline, wood.

α.	Ky.	Kx.	L/D.	M_c.	C. P.
−10	−0.00048	0.000138	−3.55	−0.0000414	....
− 8	− .00007	.000089	− .74	− .000213	....
− 6	+ .00033	.000070	+4.62	− .000296	0.934
− 4	.00070	.000062	10.24	− .000403	.588
− 2	.00107	.000079	13.60	− .000513	.476
0	.00148	.000105	14.05	− .000631	.427
+ 2	.00181	.000137	13.23	− .000730	.400
+ 4	.00216	.000174	12.42	− .000834	.382
6	.00250	.000219	11.40	− .000932	.371
8	.00284	.000267	10.65	− .00103	.359
10	.00318	.000329	9.68	− .00114	.355
12	.00343	.000384	8.95	− .00121	.350
14	.00366	.000447	8.18	− .00123	.334
16	.00214	.000679	3.16	− .000902	.357
20	.00201	.000887	2.27	− .000923	.414

TABLE III.

MODIFIED U. S. A-27-C.

(Ordinates expressed in per cent of chord.)

Per cent chord.	Ordinates.	
	Upper.	Lower.
0.00	2.35	2.35
2.50	6.475	− .175
5.00	8.900	− .375
10.00	12.000	−1.235
20.00	14.775	−2.125
30.00	15.537	−2.150
40.00	15.125	−1.800
50.00	14.000	−1.233
60.00	12.400	− .925
70.00	10.500	− .500
80.00	8.125	− .100
100.00	.875	+ .875

Radius leading edge = 1.06.
Radius trailing edge = 0.21.

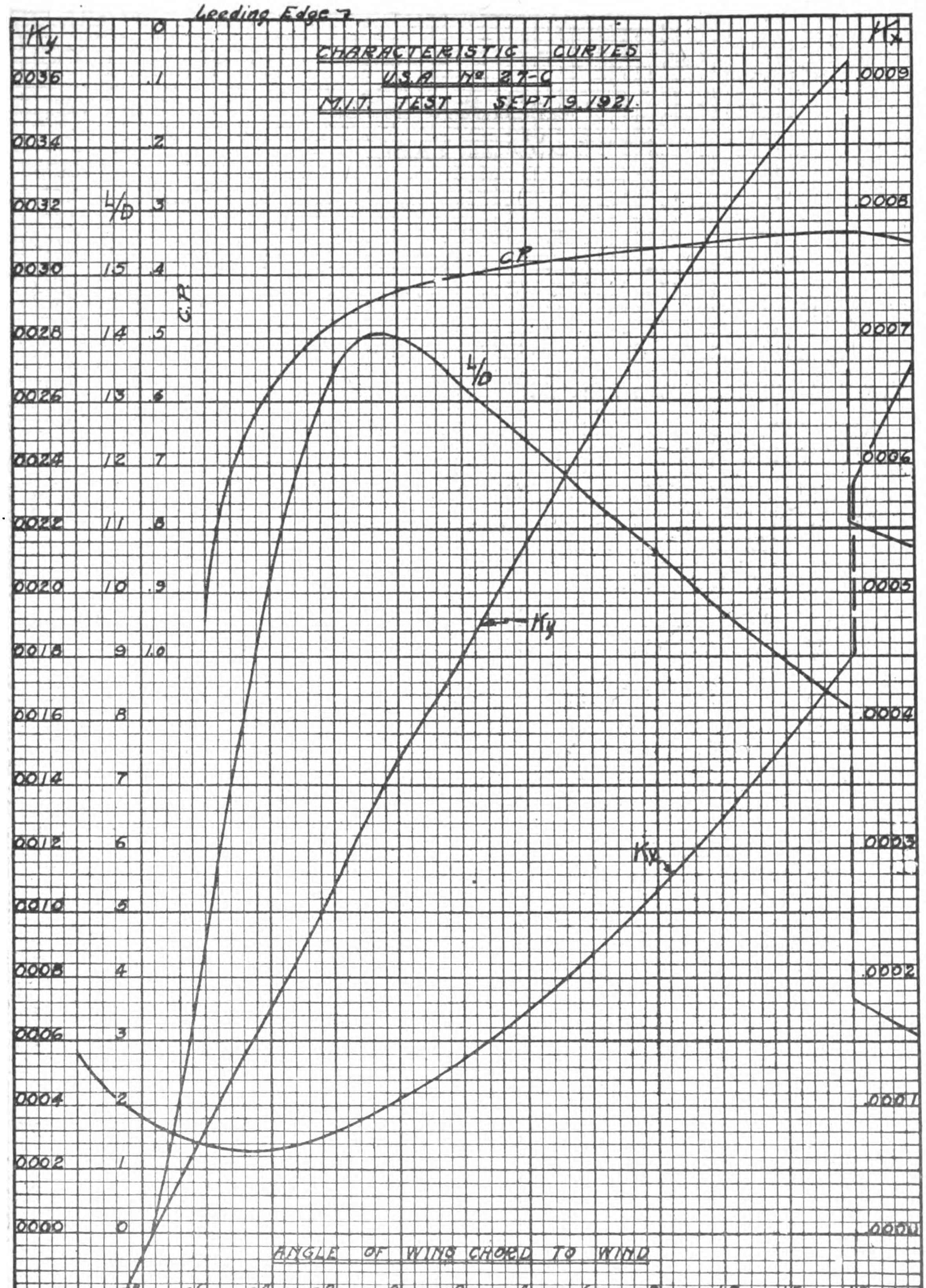
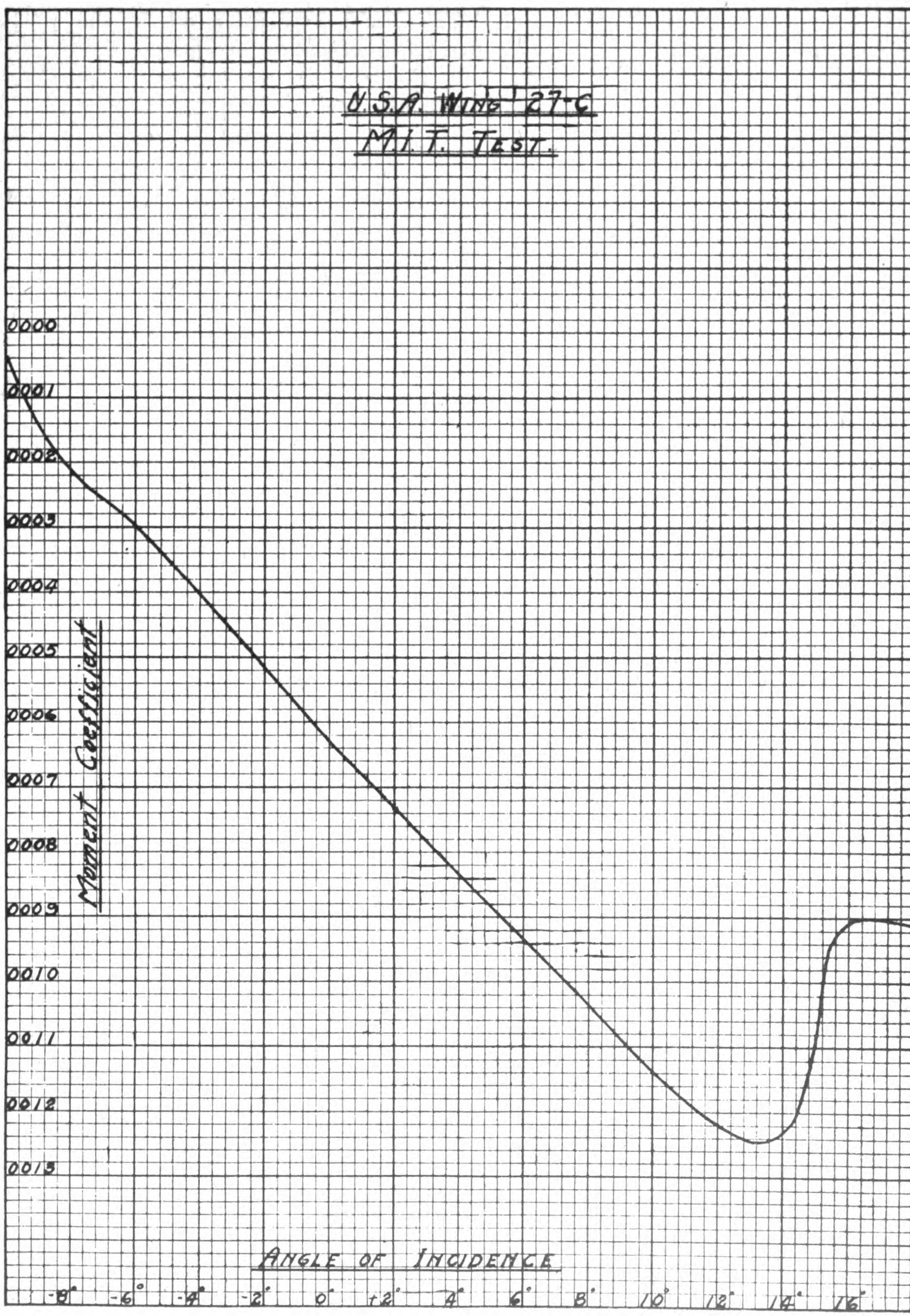

Leading Edge
CHARACTERISTIC CURVES
U.S.A. No 27-C
M.I.T. TEST SEPT 9, 1921.
Ky
Kx
L/D
C.P.
CP
L/D
Ky
Kx
ANGLE OF WING CHORD TO WIND
.0036
.0034
.0032
.0030
.0028
.0026
.0024
.0022
.0020
.0018
.0016
.0014
.0012
.0010
.0008
.0006
.0004
.0002
.0000
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
.0000
-8
-6
-4
-2
0
+2
4
6
8
10
12
14

FIG. 1.



U.S.A. WING 27-C
M.I.T. TEST.
.0000
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
Moment Coefficient
ANGLE OF INCIDENCE
-8°
-6°
-4°
-2°
0°
+2°
4°
6°
8°
10°
12°
14°
16°

FIG. 2.

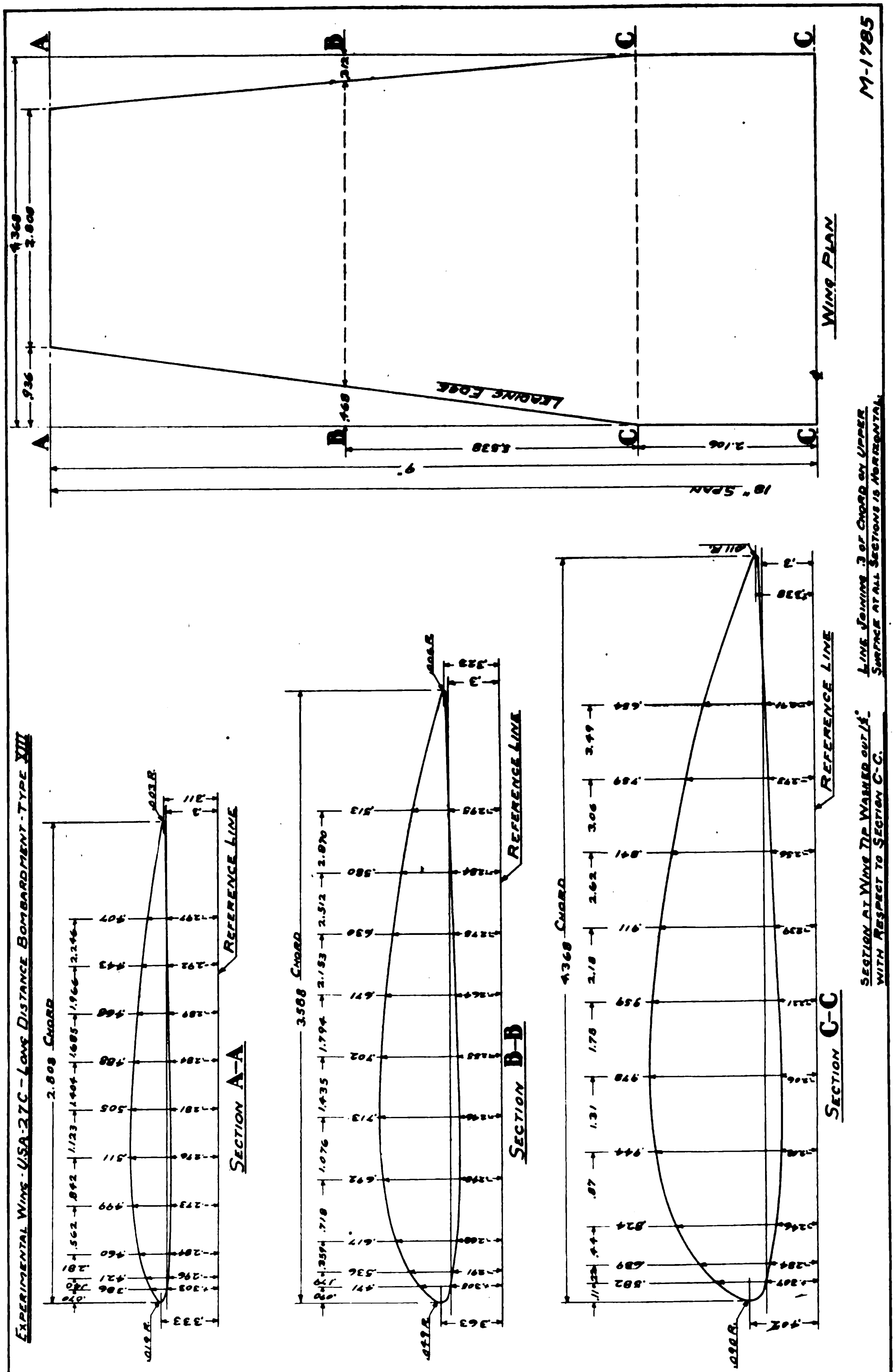

Experimental Wing · USA-27C - Long Distance Bombardment - Type XIII
Wing Plan
Leading Edge
18' Span
M-1785
Section A-A
Section B-B
Section C-C
Reference Line
Section at Wing Tip Washed out 1½° with Respect to Section C-C.
Line Joining .3 of Chord on Upper Surface at all Sections is Horizontal.

FIG. 3.

File D 10.16/5

McCOOK FIELD REPORT, SERIAL No. 1802

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | April 1, 1922 | No. 335

INVESTIGATION OF FORGED AND CAST BRASS

(MATERIAL SECTION REPORT NO. 158)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
December 14, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INVESTIGATION OF FORGED AND CAST BRASS.

PURPOSE.

To determine the suitability of forged brass in gasoline pipe line and tank fittings for service use on airplanes.

To compare the soundness of forged and cast brass fittings.

CONCLUSIONS.

Forged brass fittings are recommended for service use on airplanes where parts are standardized and can be ordered in quantity. For other than a production basis, the cost of forged brass parts would be prohibitive as compared to the sand cast.

Forged brass has a greater tensile strength, is harder, and less porous than cast brass.

MATERIAL.

The following brass forgings submitted by the Mueller Metal Co., Port Huron, Mich.:

Specimen No.	Part.
1	Forged brass cylinder plug, manufactured by the Delco Light Co.
2	Forged brass sediment bowl, manufactured by the Michigan Stamping Co.
3	Forged brass flared tube and nut, manufactured by the Olds Motor Works.
4	Forged brass elbow, manufactured by the White Motor Co.
5	Forged brass vacuum elbow, manufactured by the Olds Motor Works.

The following fittings made in the Metals Branch Foundry in addition to several metallographic samples taken from routine foundry melts of gun metal:

Specimen No.	Part.
6	Cast brass $\frac{3}{4}$-inch elbow.
7	Cast brass $\frac{3}{4}$-inch T.

Specimen No. 8 was selected at random from the stockroom.

PROCEDURE.

CHEMICAL ANALYSIS.

The outline of procedure was to determine the chemical composition of specimens Nos. 2 and 4 which were submitted by the Mueller Metal Co. The chemical composition of specimens Nos. 6 and 7, which were cast in the Metals Branch Foundry, were obtained from the foundry record of the melts from which these parts were cast. The composition of the fitting obtained from stock was not determined.

METALLOGRAPHIC.

All specimens were prepared for examination according to standard practice and etched with NH_4OH and H_2O_2. Specimens from forged brass were taken parallel and at right angles to direction of forging. The polished but unetched specimens were carefully examined for blowholes, segregates of oxides and other impurities. Microphotographs were made of representative specimens. Specimen No. 2 was annealed for 2 hours at 1400 deg. F. and allowed to cool with the furnace in order to determine if the forged brass had been subjected to an anneal subsequent to forging.

PHYSICAL TESTING.

Scleroscope hardness tests were made on all specimens and Brinell hardness was obtained on specimens Nos. 1, 2, and 8. Material for strength test was not available.

STRAIN TEST.

Specimens were first subjected to a preliminary treatment by immersing for five seconds in a 5 per cent aqueous solution of HNO_3 and then pickled for five hours in a 0.1 per cent solution of mercurous nitrate ($HgNO_3$) in water.

RESULTS.

The results of the chemical analysis are depicted in Table I.

TABLE I.

Specimen No.	Tin.	Lead.	Copper.	Zinc.	Iron.
1			[1]		
2	0.30	2.76	57.88	Diff.	0.31
3			[1]		
4	.47	2.35	59.00	Diff.	.37
5			[1]		
6	9.87	Nil.	88.40	1.30	.16
7			[1]		
8			[1]		

[1] Not determined.

METALLOGRAPHIC.

Representative micrographs are shown in figures 669–1 to 669–8, inclusive. The structure of the material submitted by the Mueller Metals Co. (figs. 669–1 to 669–5, inclusive), resembles that of extruded Muntz metal. The irregular orientation of the alpha and beta structure shows the effects of the forging. This is more pronounced in sections that have been subjected to more work than others, such as the portion adjacent to the point of minimum radius of curvature in the forged elbows (see fig. 669–2). There is no indication in the microstructure of cold work. The annealed specimen showed frequent

twinning of the alpha constituent. The lead in these specimens could easily be distinguished at a magnification of 500 diameters and is evenly distributed through both the alpha and beta structures. The forged specimens were free from blowholes, cold shuts, and segregations of foreign matter.

The structure of the material cast in the Metals Branch Foundry is typical of cast gun metal. The dark cores are the copper rich alpha solution, and the small light areas, readily seen at a magnification of 500 diameters, are the alpha delta copper-tin constituent (see figs. 669–6 and 669–7). Blowholes could be distinguished in the unetched specimens. In some they were quite numerous, others quite rare. In a few cases there was evidence of inclusions of oxides in the specimens taken from routine foundry melts.

The structure of the fitting taken from stock indicates that the brass used was high in lead and very much inferior to either material used by the Mueller Metal Co. or the Metals Branch Foundry. There is evidence of segregation or liquation of the lead along the grain boundaries. Specimen which was annealed for two hours at 1,400° F. showed frequent twinning of the alpha constituent.

PHYSICAL TESTING.

Results of the hardness tests are given below in Table II.

TABLE II.

Specimen No.	Part.	Scleroscope.	Brinell.
1	Cylinder plug	23	98
2	Sediment bowl	18	80
3	Flared tube and nut	26	....
4	Elbow	29	....
5	Vacuum elbow	21	....
6	Cast elbow	22.7	70
7	Cast T	19	65
8	Cast T (stock)	14	....

STRAIN TEST.

Results of the strain test were negative in all cases. After five hours' immersion in the mercurous nitrate solution, the specimens were evenly coated with metallic mercury, but there were no signs of cracks.

DISCUSSION OF RESULTS.

The chemical analysis shows that the metal used in the forgings is of the Muntz metal type and is within the range of composition recommended for hot forgings or stamping by Guillet. Although the manufacturer claims that the forging of brass is a new process, brass has been successfully hot forged or stamped in England for several years. It is known that there is danger of producing internal strains which result in season or spontaneous cracks. This condition is usually caused by forging at too low a temperature and can be readily detected in either the microstructure or by the mercurous nitrate test. Unless the cold work has been too severe, it may be remedied by annealing at a temperature ranging 600° to 800° F. The twinning of the alpha constituent in the annealed specimen indicates that this material has not been annealed subsequent to the forging operation. Another source of trouble encountered by the use of forged brass is the unequal hardness of different lots of metal which seriously slows up the speed of machining when the parts are being turned out on production basis. The variation in hardness is usually contributed to the chemical composition and so can be controlled. The hardness tests and the chemical composition of the forged fittings under test indicate that fittings made of this material could be readily machined.

It may be observed that the fittings cast in the Metals Branch Foundry are of tin bronze and not brass. The reason for this is that although the copper-tin alloy is more expensive, it gives a sounder casting and is more desirable for parts that are to hold water or gasoline. For that reason the gun metal rather than the red brass cast in Metals Branch Foundry was taken as a basis with which to compare the forged brass. The properties of forged and cast brass are not really comparable, as the effect of either hot or cold work on a metal is well known, and it is to be expected that the forged material would be far superior to the cast. The particular forgings under test were forged from extruded bars so that the product is a result of two processes of hot working along with the necessary annealing, all of which tends to produce a material more homogeneous and sound than that which is used in the final product as cast.

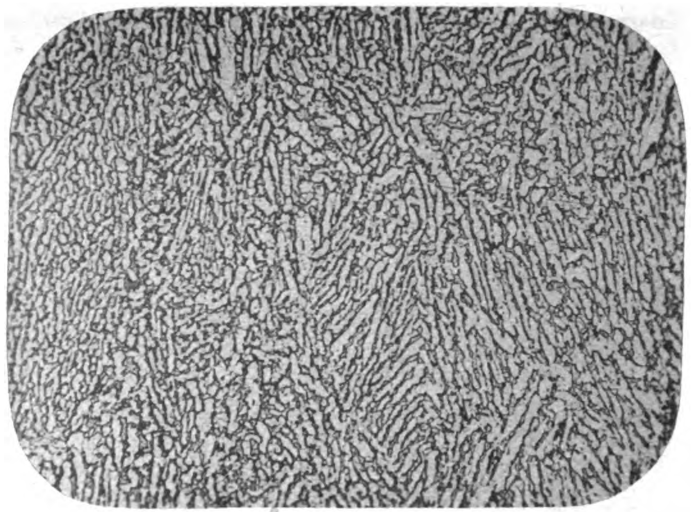


FIG. 669-1.—Magnification 100 diameters. Etching $NH_4OH+H_2O_2$. Remarks: Section from specimen 3.

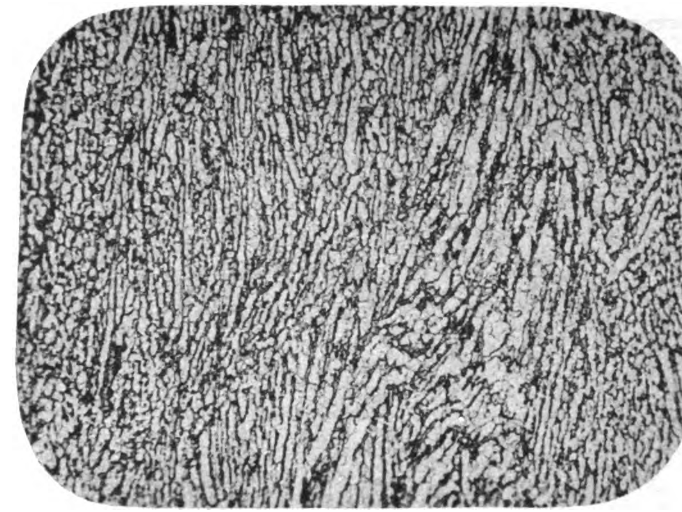


FIG. 669-2.—Magnification 100 diameters. Etching $NH_4OH+H_2O_2$. Remarks: Section taken from specimen 3 at the point of maximum radius of curvature.

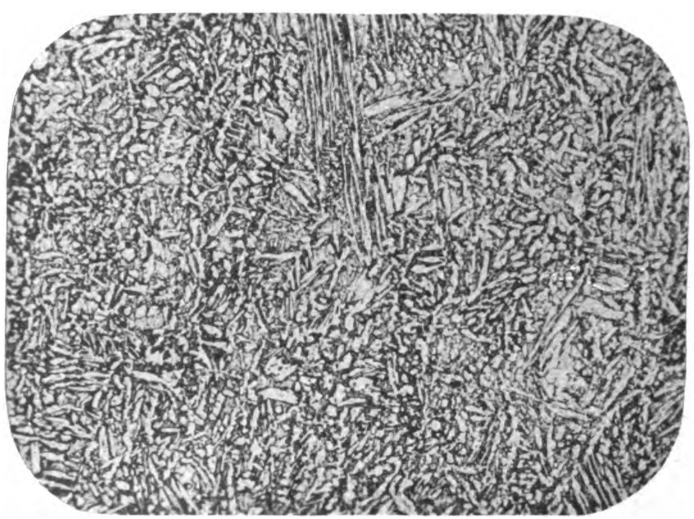


FIG. 669-3.—Magnification 100 diameters. Etching $NH_4OH+H_2O_2$. Remarks: Section taken from specimen 2 at right angles to direction of forging.

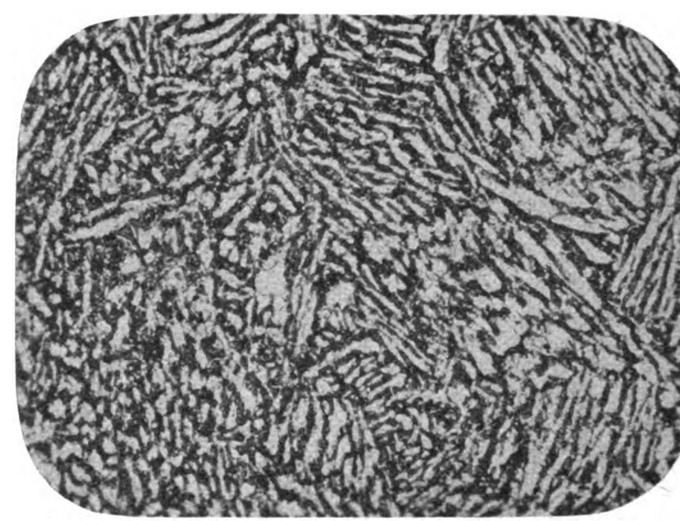


FIG. 669-4.—Magnification 100 diameters. Etching $NH_4OH+H_2O_2$. Remarks: Section taken from specimen 4, parallel to direction of forging.

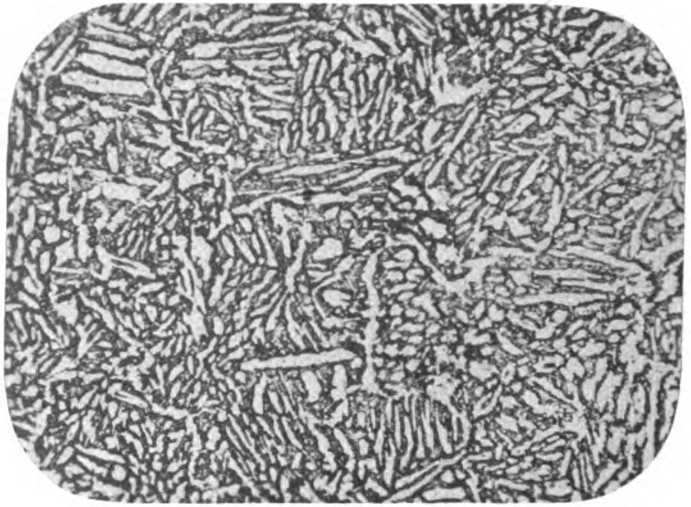


FIG. 669-5.—Magnification 100 diameters. Etching $NH_4OH+H_2O_2$. Remarks: Section taken from specimen 4 at right angles to direction of forging.

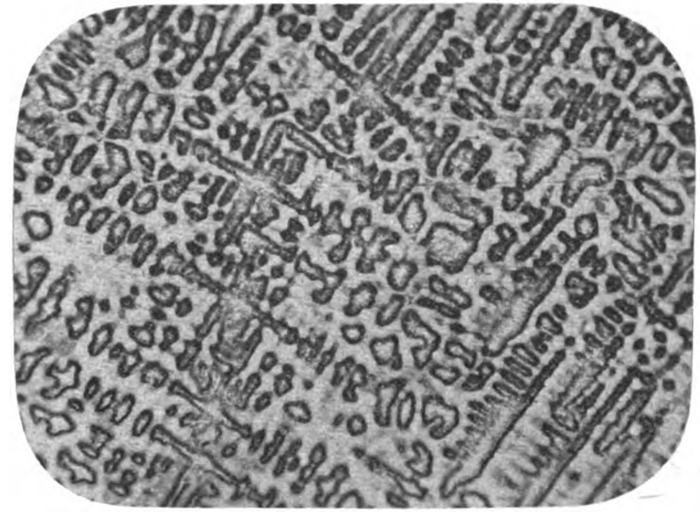


FIG. 669-6.—Magnification 100 diameters. Etching $NH_4OH+H_2O_2$. Remarks: Section from specimen 6. Structure typical cast gun metal. Dark cores of copper rich solution.

FIG. 669-7.—Magnification 100 diameters. Etching $NH_4OH+H_2O_2$. Remarks: Section from specimen 7. Cast gun metal.

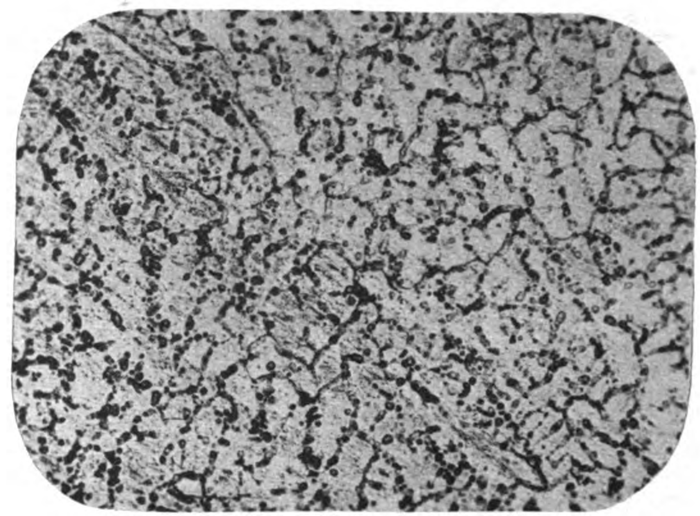


FIG. 669-8.—Magnification 100 diameters. Etching $NH_4OH+H_2O_2$. Remarks: Section from specimen 8. Lead and pits show dark.

File D 11.31/50

McCOOK FIELD REPORT, SERIAL No. 1804

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV April 1, 1922 No. 336

EFFECT OF FUEL HEAD AT CARBURETOR, ON BRAKE HORSEPOWER AND BRAKE SPECIFIC FUEL CONSUMPTION

(POWER PLANT SECTION REPORT)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
December 19, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

EFFECT OF FUEL HEAD AT CARBURETOR, ON BRAKE HORSEPOWER AND BRAKE SPECIFIC FUEL CONSUMPTION.

OBJECT.

To determine the relation between fuel head at the carburetor and the horsepower and fuel consumption of an engine, and to determine the maximum and minimum practicable heads for several types of service carburetors.

SUMMARY OF RESULTS.

The effect on the horsepower and fuel consumption of an engine of increasing the fuel head at the carburetor may be summarized as follows:

STROMBERG NA-D6 CARBURETOR.

Minimum operating head, 12 inches of gasoline.[1]

Horsepower remains practically constant between minimum head and static flooding point with a slight increase in fuel consumption with increased head.

Does not flood at 8 pounds per square inch pressure.

PACKARD ZENITH U. S. 54 CARBURETOR.

Minimum operating head, 6.3 inches of gasoline.

Horsepower remains practically constant between minimum head and static flooding point with a slight increase in fuel consumption up to a head of 2 pounds per square inch and a more marked increase between heads of 2 and 4 pounds per square inch.

Does not flood at head of 8 pounds per square inch.

ZENITH U. S. 52 CARBURETOR (LIBERTY).

Minimum operating head, 40 inches of gasoline.

Marked increase in horsepower from 8 to 40 inch heads.

Horsepower practically constant between heads of 2 pounds per square inch and 8 pounds per square inch.

Fuel consumption in general increases with carburetor head.

Does not flood at 8 pounds per square inch pressure.

STROMBERG NA-L5 CARBURETOR.

Minimum operating head, 12 inches of gasoline.

Horsepower and fuel consumption practically constant between heads of 12 inches of gasoline and 5 pounds per square inch pressure.

Floods at head of 4.4 pounds per square inch pressure.

METHOD OF TEST.

Tests were conducted on the model "H" Hispano-Suiza engine equipped with a Stromberg NA-D6 carburetor, the model 1A-1237 Packard engine fitted with the Packard Zenith U. S. 54 carburetor, the Liberty "12" engine fitted with the Stromberg NA-L5 (inverted) carburetor, and the Liberty "12" with the Zenith U. S. 52 carburetor. The engines were coupled to an electric cradle dynamometer and tested at normal speed full throttle for horsepower and fuel consumption with varying fuel heads.

The apparatus for varying the fuel head at the carburetor consists of a portable fuel tank, mounted on scales, with an air line connection for controlling the pressure on the fuel in the tank. The head at the carburetor was measured with a mercury manometer connected to the fuel line. The gasoline level in the float chamber was observed by means of a sight gauge which was vented back to the top of the float chamber.

The flooding point was determined on several carburetors of each model before the engine was started by increasing the fuel head until gasoline overflowed from the jets. The engine was then run at the normal speed, full throttle, and the minimum head determined which would give regular operation. Further runs were then made varying the head of gasoline between the minimum head and the static flooding point. Since the change of engine performance between the limits in the tests was confined mainly to the vicinity of the minimum head, small increments of change in the gasoline head were taken about that point and large increments taken over the main part as shown by the curves, figures 1 to 4.

The Stromberg NA-D6 on the model "H" Hispano-Suiza and the Packard Zenith and the U. S. 54 on the Packard 1A-1237 were tested taking a comparatively large number of readings, but the tests in general conformed to the above description.

All runs were made with the mixture control in the full rich position.

All standard power and fuel consumption readings, as outlined in Engineering Division report, serial No. 1507, were taken at each pressure increment.

RESULTS OF TEST.

The results of the test are shown in the curves, figures 1, 2, 3, and 4, and the data tables, page 4. It will be noted that the Zenith U. S. 52 carburetor is more sensitive to changes in fuel head than the other three carburetors tested, especially between 8 inches and 40 inches head of gasoline. The horsepower increase throughout this range was approximately 4 per cent, and the fuel consumption increase was 10 per cent. Forty inches was, therefore, taken as the minimum head, although the engine would operate at lower heads with some loss in power. The fuel head change had only slight effect on the horsepower output of the engines equipped with the Stromberg NA-D6, Packard-Zenith, and the Stromberg NA-L5 carburetors producing a maximum variation of approximately 1 per cent in the case of the Stromberg NA-L5 carburetor. An increase in fuel head caused a slight increase in fuel consumption of the engines equipped with the Stromberg NA-D6 and the Packard-Zenith and a very slight decrease in the fuel consumption with the Stromberg NA-L5.

It is recommended that these carburetors be operated with gasoline pressures safely above the minimum values given under "Summary of Results."

[1] The "minimum operating head" is the lowest head giving normal operation at full throttle, normal speed.

93902—22

Model "H" Hispano-Suiza engine, Stromberg NA-D6 carburetor.

Fuel head.		Corrected horsepower at 1,800 R. P. M.	Carburetor air, temperature °F.	Fuel consumption.	
Gasoline (inches).	Pressure, pounds per square inch.			Pounds per hour.	Pounds per horsepower hour.
6.0	0.15	319.5	79	193.0	0.621
12.0	.30	318.0	82	204.0	.667
18.0	.45	319.2	81	206.1	.670
24.0	.60	317.5	81	206.0	.665
30.0	.75	317.5	84	203.0	.663
36.0	.90	319.5	86	202.9	.656
48.0	1.20	318.6	88	203.5	.663
60.0	1.50	316.0	89	205.4	.680
79.6	2.00	318.7	83	206.1	.671
99.4	2.50	319.7	80	204.0	.659
119.4	3.00	318.5	81	205.9	.670
139.5	3.50	319.0	74	207.1	.677
159.4	4.00	316.9	79	207.1	.675
179.2	4.50	318.6	78	207.0	.575
199.0	5.00	315.0	83	208.2	.684
239.0	6.00	316.0	84	209.4	.686
278.8	7.00	315.1	87	204.2	.673
318.2	8.00	317.5	79	208.9	.682

Packard 1A-1237 engine with Packard-Zenith, U. S. 54 carburetor.

Fuel head.		Horsepower corrected to 1,800 R. P. M. and 29.92 In. Hg., average.	Carburetor air, temperature °F.	Average fuel consumption.	
Gasoline (inches).	Pressure, pounds per square inch.			Pounds per hour.	Pounds per horsepower hour.
6.3	0.157	352.1	84 84	180.2	0.526
12.2	.304	351.9	84 84	176.5	.520
18.0	.451	351.8	84 84	177.7	.520
24.3	.608	352.8	85 85	172.5	.507
30.2	.754	352.8	86 86	177.9	.529
36.1	.902	353.3	86 86	178.7	.523
48.4	1.21	352.5	88 88	178.2	.524
60.4	1.51	352.8	88 88	179.5	.527
80.0	2.00	351.7	86 88	178.8	.528
100.0	2.50	352.8	86 86	181.8	.539
120.0	3.00	351.8	86 87	182.4	.539
140.0	3.50	348.8	88 88	180.5	.537
160.0	4.00	349.2	88 88	183.8	.548
180.0	4.50	355.5	76 76	184.6	.531
200.0	5.00	356.5	78 78	182.7	.529
240.0	6.00	357.3	78 78	187.7	.544
280.0	7.00	355.3	78 78	188.5	.542
320.0	8.00	355.8	78 79	184.6	.534

Liberty 12 engine, Stromberg NA-L5 carburetor.

Fuel head.		Corrected horsepower at 1,700 R. P. M.	Carburetor air, temperature °F.	Fuel consumption.	
Gasoline (inches).	Pressure, pounds per square inch.			Pounds per hour.	Pounds per horsepower hour.
3.9	0.098	356.2	82	162.2	0.474
7.8	.196	417.5	82	189.4	.464
7.8	.196	422.0	82	189.6	.450
135.2	3.38	422.5	82	193.5	.469
256.8	6.42	422.5	82	191.5	.464
262.9	6.57	425.0	82	191.5	.464
376.4	9.41	425.5	82	192.5	.468
378.4	9.46	421.0	80	191.5	.468

Liberty 12 engine with Zenith U. S. 52 carburetor.

Fuel head.		Horsepower corrected to 1,700 R. P. M. and 29.92 In. Hg. average.	Carburetor air, temperature °F.	Fuel consumption.	
Gasoline (inches).	Pressure, pounds per square inch.			Pounds per hour average.	Pounds per horsepower hour average.
5.9	0.147	370.3	90	184.3	0.507
5.9	.147		92		
5.9	.147		92		
13.7	.343	392.5	90	204.3	.532
13.7	.343		90		
21.5	.539	394.9	91	207.2	.537
21.5	.539		94		
84.4	2.11	393.8	94	213.9	.552
84.4	2.11		92		
154.8	3.87	389.7	93	212.8	.556
154.8	3.87		93		
241.2	6.03	391.2	93	219.6	.572
237.2	5.93		94		
311.6	7.79	389.4	91	222.5	.585
311.6	7.79		92		

Carburetor settings.

	Choke.	Main jet.	Comp. jet.
Stromberg NA-D6	1-13/16 in.	No. 32 drill.	
Packard-Zenith U. S. 54	36 mm.	2.10 mm.	2.15 mm.
Stromberg NA-L5 (single Venturi).	1-5/8 in.	No. 42 drill.	
Zenith U. S. 52	36 mm.	1.65 mm.	1.70 mm.

NOTE.- The mixture control was set in the full rich position for all runs.

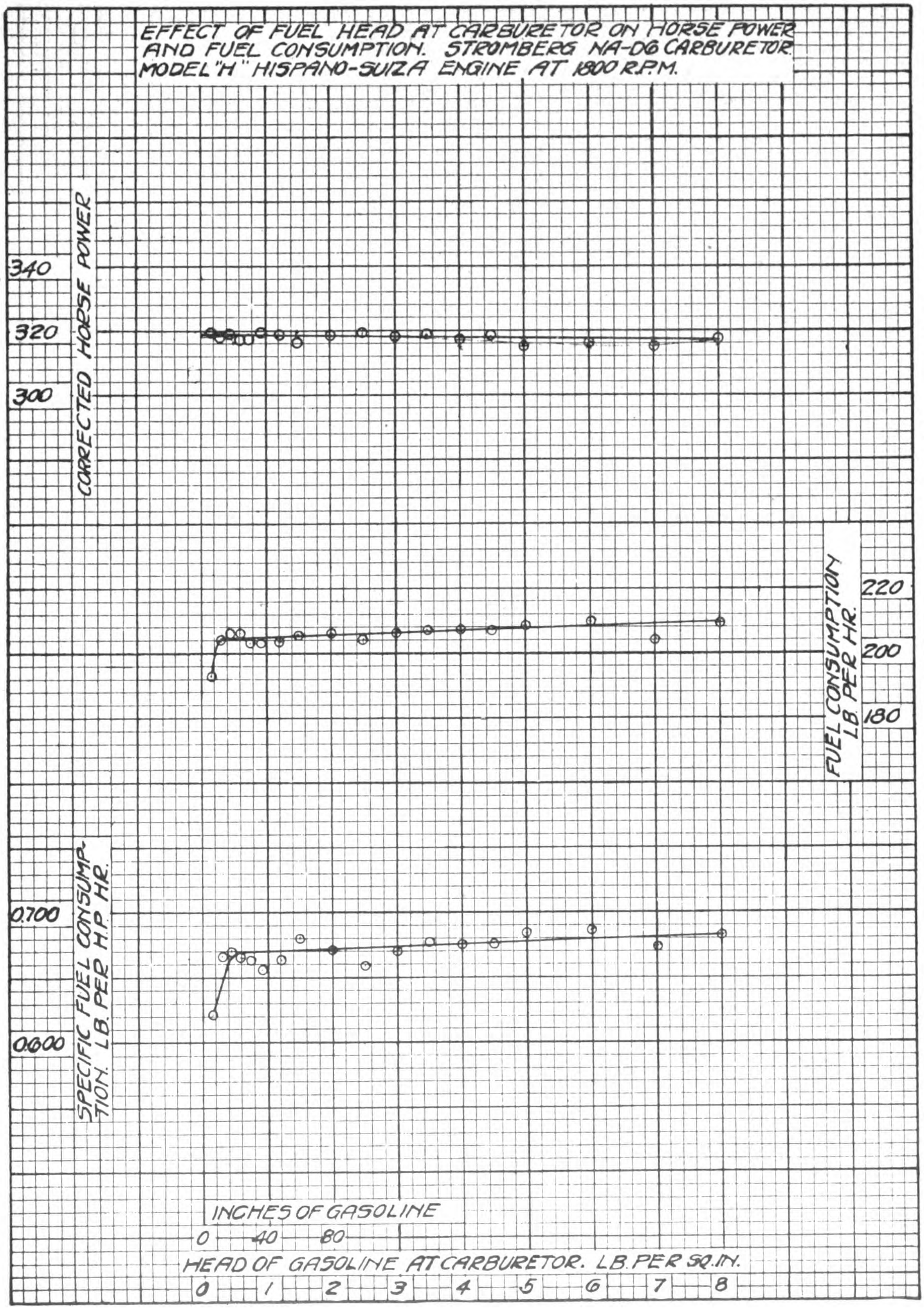
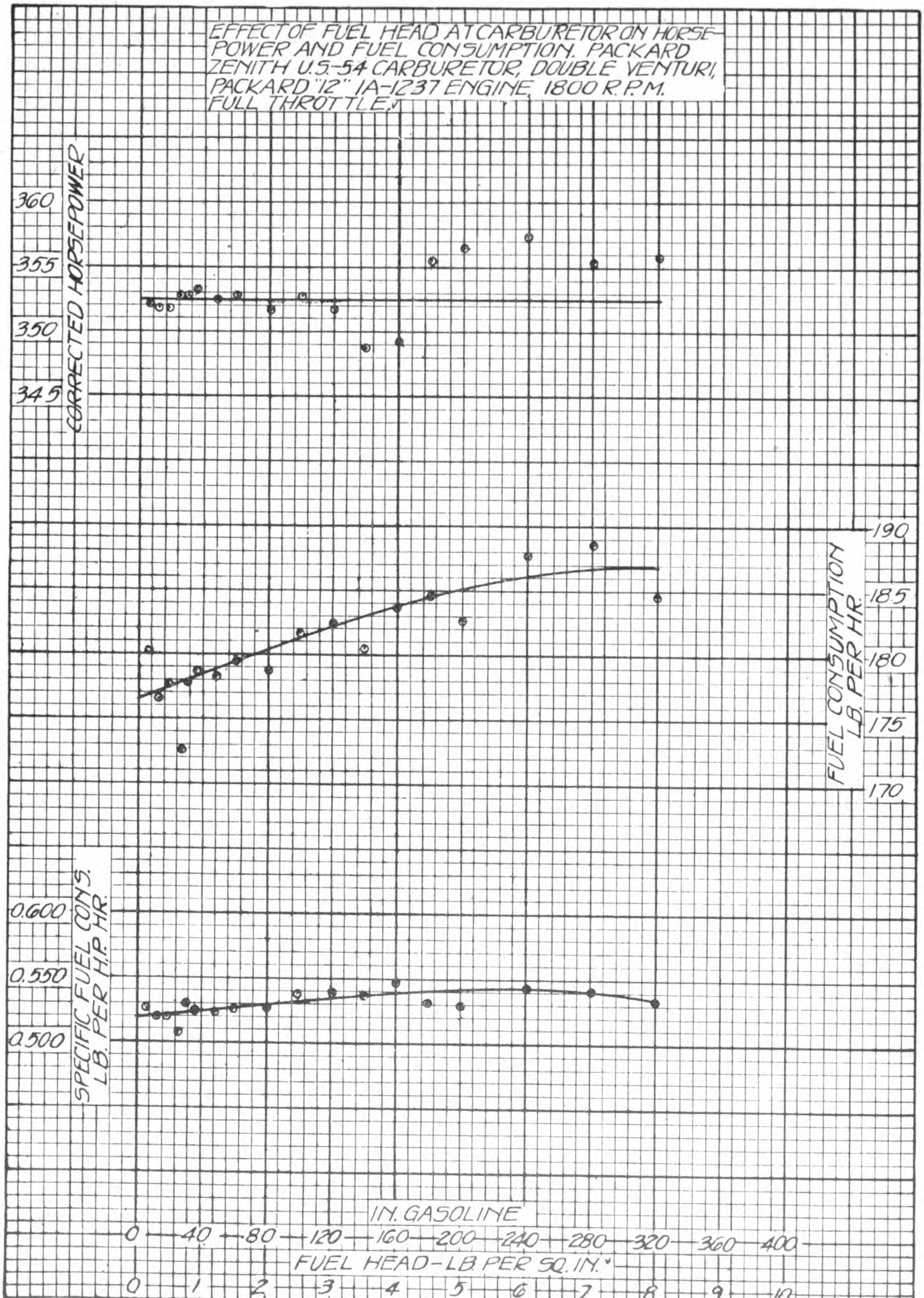

EFFECT OF FUEL HEAD AT CARBURETOR ON HORSE POWER AND FUEL CONSUMPTION. STROMBERG NA-D6 CARBURETOR MODEL "H" HISPANO-SUIZA ENGINE AT 1800 R.P.M.
CORRECTED HORSE POWER
340
320
300
FUEL CONSUMPTION LB. PER HR.
220
200
180
SPECIFIC FUEL CONSUMPTION. LB. PER H.P. HR.
0.700
0.600
INCHES OF GASOLINE
0
40
80
HEAD OF GASOLINE AT CARBURETOR. LB. PER SQ. IN.
0
1
2
3
4
5
6
7
8

Fig. 1.



EFFECT OF FUEL HEAD AT CARBURETOR ON HORSEPOWER AND FUEL CONSUMPTION. PACKARD ZENITH U.S.-54 CARBURETOR, DOUBLE VENTURI, PACKARD "12" 1A-1237 ENGINE, 1800 R.P.M. FULL THROTTLE.
CORRECTED HORSEPOWER
360
355
350
345
FUEL CONSUMPTION LB. PER HR.
190
185
180
175
170
SPECIFIC FUEL CONS. LB. PER H.P. HR.
0.600
0.550
0.500
IN. GASOLINE
0
40
80
120
160
200
240
280
320
360
400
FUEL HEAD - LB PER SQ. IN.
0
1
2
3
4
5
6
7
8
9
10

Fig. 2.

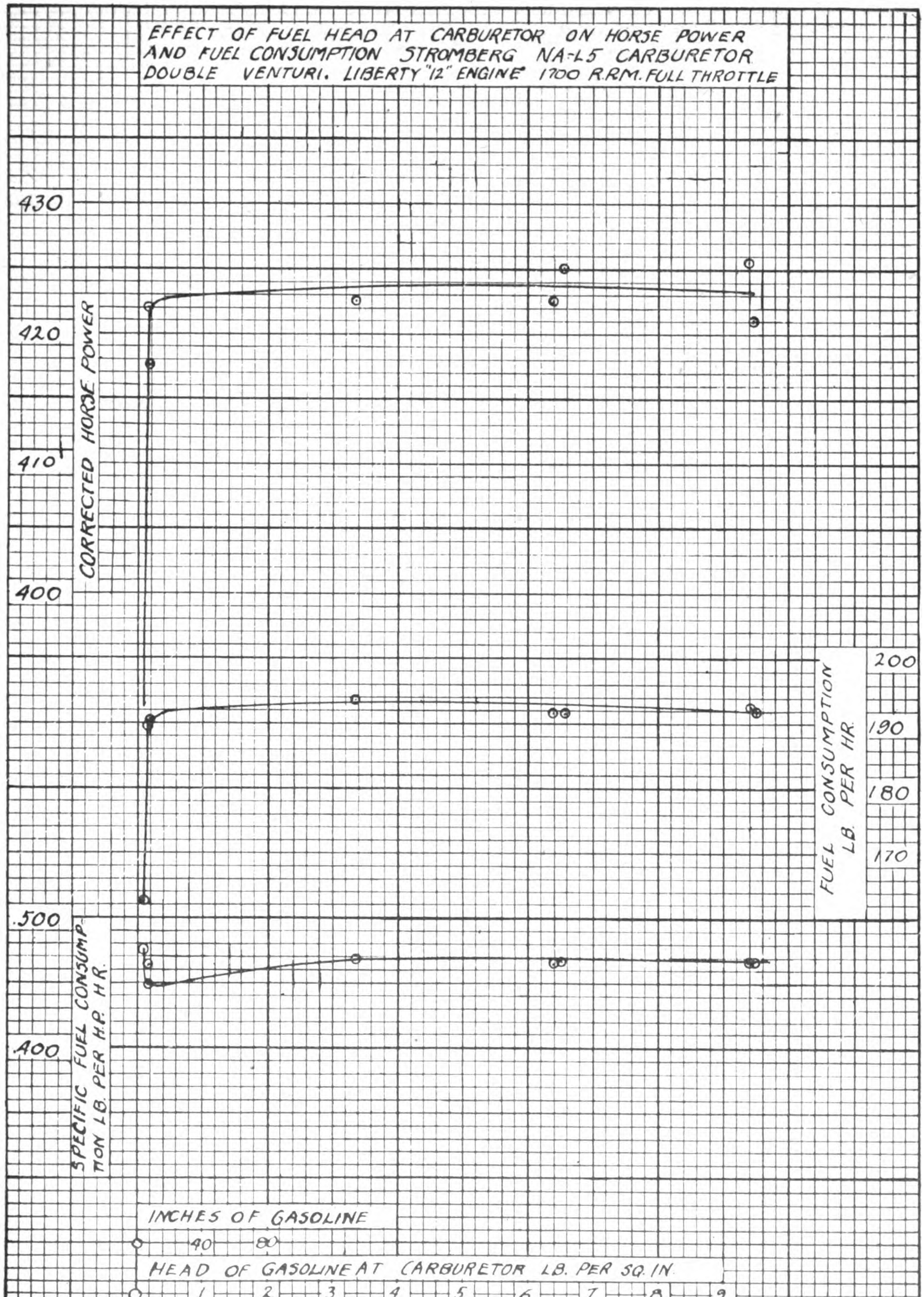

EFFECT OF FUEL HEAD AT CARBURETOR ON HORSE POWER AND FUEL CONSUMPTION STROMBERG NA-L5 CARBURETOR DOUBLE VENTURI. LIBERTY "12" ENGINE 1700 R.P.M. FULL THROTTLE
CORRECTED HORSE POWER
430
420
410
400
FUEL CONSUMPTION LB. PER HR.
200
190
180
170
SPECIFIC FUEL CONSUMPTION LB. PER H.P. HR.
.500
.400
INCHES OF GASOLINE
0
40
80
HEAD OF GASOLINE AT CARBURETOR LB. PER SQ. IN.
0
1
2
3
4
5
6
7
8
9

FIG. 3.

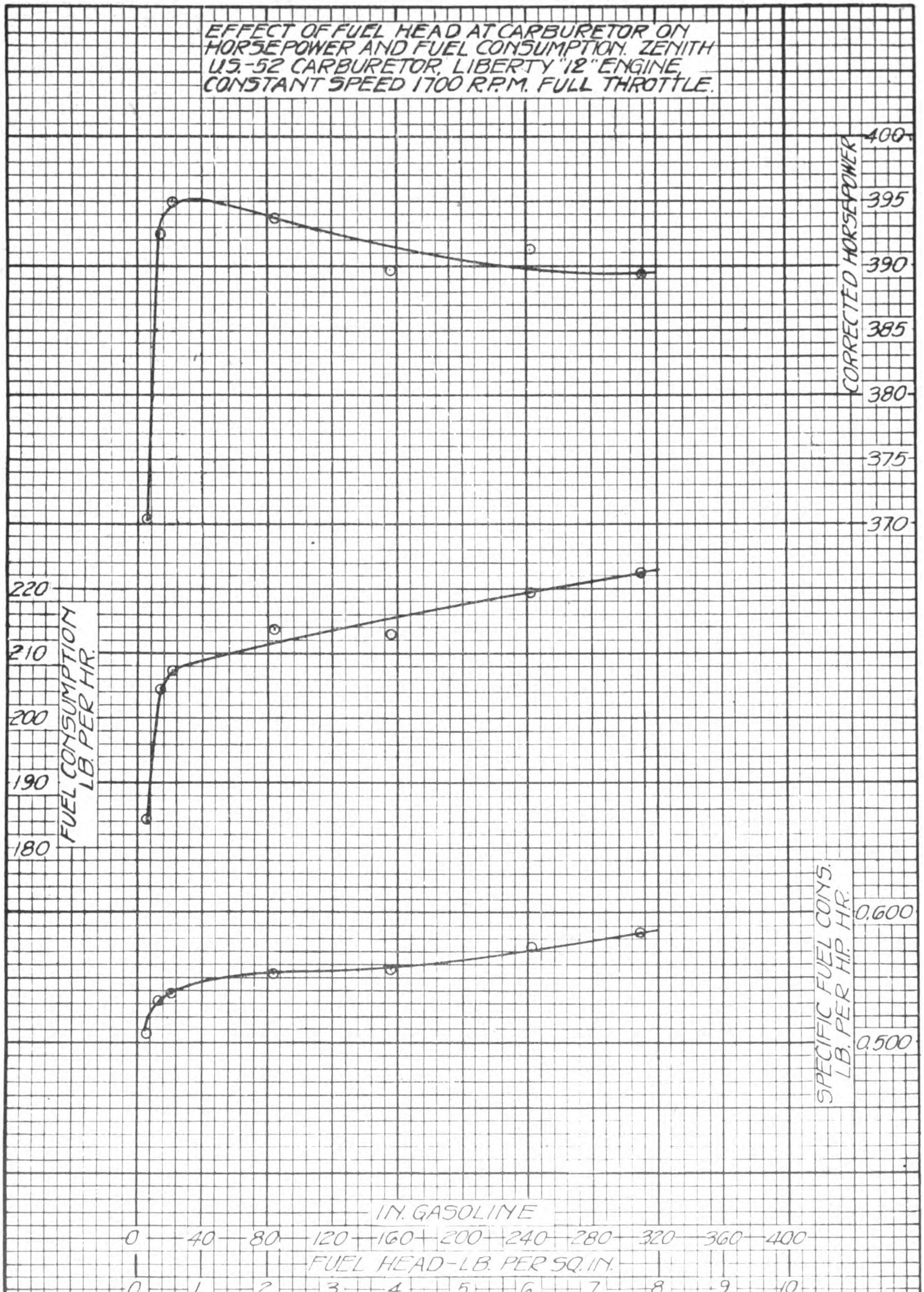

EFFECT OF FUEL HEAD AT CARBURETOR ON HORSEPOWER AND FUEL CONSUMPTION. ZENITH U.S.-52 CARBURETOR, LIBERTY "12" ENGINE CONSTANT SPEED 1700 R.P.M. FULL THROTTLE.
CORRECTED HORSEPOWER
400
395
390
385
380
375
370
FUEL CONSUMPTION LB. PER HR.
220
210
200
190
180
SPECIFIC FUEL CONS. LB. PER H.P. HR.
0.600
0.500
IN. GASOLINE
0 40 80 120 160 200 240 280 320 360 400
FUEL HEAD-LB. PER SQ. IN.
0 1 2 3 4 5 6 7 8 9 10

FIG. 4.

File D10.13/69

McCOOK FIELD REPORT, SERIAL No. 1809

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | April 1, 1922 | No. 337

THE ECONOMICAL USE OF DURALUMIN AS A SUBSTITUTE FOR STEEL IN COMPRESSION

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 25, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

THE ECONOMICAL USE OF DURALUMIN AS A SUBSTITUTE FOR STEEL IN COMPRESSION.

GENERAL DISCUSSION OF PROBLEM.

Duralumin can not be intelligently substituted for steel without some knowledge of the variation in the weight ratios for equal strength with changes of load, length, l/ρ, and end fixity. To enable the designer to choose readily between duralumin and steel for the lightest weight, this report has been produced embodying a study of weight ratios for common loads, lengths, and fixities. From the curves herein contained the designer may quickly choose between duralumin and steel if there has been obtained some preliminary knowledge of the load, length, or approximate size of the structure in question.

A study of curves of allowable compressive strengths will show that the proportionate loss in strength with increased values of l/ρ is not the same for all materials. For example, steels having a yield point in compression higher than 90,000 pounds per square inch lose strength more rapidly than does duralumin having a yield point of 30,000 pounds per square inch. Tubes of equal strength of duralumin and steel, by reason of the difference in unit stresses, will be of different sizes and will have correspondingly different values of ρ.

These two variables, loss of column strength and variation in values of ρ must be taken into account when studying the variation of the weight ratios of struts or other compression members.

METHOD OF STUDY OF PROBLEM.

The only structural form considered in this report is the tube. In order to make the results more comparable, a ratio of diameter to thickness of 18.75 was adopted, and in all the computations theoretical sizes and section properties were used. Because of the necessity of using standard tubes in actual design, the ratios of diameter to thickness for comparative designs will not be constant, and consequently the weight ratios will vary slightly from those given in this report, not enough, however, to affect their validity for preliminary designs.

PRESENTATION OF RESULTS.

The results of this investigation are presented in two forms. The first (figures 1 and 2) consists of curves of weight ratios plotted against values of l/ρ for steel with a companion curve of values of l/ρ for duralumin plotted against values of l/ρ for steel.

To use the cuves in figure 1, the value of l/ρ for the steel member must be known. If it should happen that the available data is for duralumin, the curves in figure 2 will give the corresponding values for steel, and figure 1 may then be used to determine the relative weights of the two designs.

The second form is a series of curves of weight ratios plotted against load (figures 3, 4, 5). Two sets of curves for different lengths have been plotted for each steel specification, one for $C=1$, and a second $C=2$. These curves will afford a rapid method of comparing the relative weights of steel and duralumin designs if the loads and the lengths are known. For cases not covered by these curves recourse must be made to figures 1 and 2.

From the curves in figure 1 it will be seen that pin-ended steel struts having a yield point of 90,000 pounds per square inch with an l/ρ of less than 33 will be lighter than duralumin of equal strength, and that the advantage of the steel will extend up to higher values of l/ρ as the yield point of the steel is increased by special heat treatments. A comparison of the curves for $C=1$ and $C=2$ will show that the range of superiority of the steel will also be extended by increasing the end fixity.

EFFECT OF LIMITATION OF CENTER HEIGHT.

A third variable affecting the weight ratios is the limitation of center height of spars by the wing section. The sizes of the flange members are determined by the moment at the section and the center to center distance of the flanges. In an internally braced monoplane wing where the stress is all bending, the use of the larger duralumin tubes instead of the smaller steel tubes may cut down the center to center distance of the flanges sufficiently to increase the flange stress 8 to 10 per cent. The attendant increase in the weight of duralumin raises the curves of weight ratios by an amount depending upon the spar depth. For spar design a fixity of 2 is usually assumed so that the curves of weight ratio will always lie above that for $C=2$. A comparison of weights of steel and duralumin wing spars for the CO-3 is given in the appendix; the decrease in the center to center distance of the flanges is illustrated in figure 6.

The above conclusions are based upon an assumed value of 30,000 pounds per square inch as the yield point in compression for duralumin, a value sightly higher than 27,000 pounds per square inch allowed by the Air Service Specifications. The Air Service figure is conservative, and will probably be increased in the near future to 30,000 or even 35,000 pounds per square inch.

APPENDIX NO. 1.

COMPUTATIONS FOR CURVES IN FIGURES 1 TO 5.

The first step was to design a number of tubes 10 inches in length for loads varying from 500 pounds to 40,000 pounds. These tubes gave values of l/ρ varying from 14 to 112. The allowable stresses used were taken from the column curves based upon the combined Johnson and Euler curves as used by the Engineering Division of the Air Service. From these computations, figures 1 and 2 were plotted. Subsequently, the work was repeated for lengths of 20, 30, 40, and 50 inches from which figures 3, 4, and 5 were plotted. As the sizes could only be obtained by a series of approximations, the following formulas were used for the section properties:

$$(1)\ \frac{D}{t}=18.75.$$

$$(2)\ A=\frac{\text{Load}}{\text{allow. } f_c}=\pi Dt=\frac{\pi D^2}{18.75}.$$

$$(3)\ I=\frac{\pi D^3 t}{8}.$$

$$(4)\ \rho=\sqrt{\frac{I}{A}}=\sqrt{\frac{D^2}{8}}=\sqrt{.745A}.$$

The following shows the method of calculating and comparing results worked out for duralumin and 90,000 pounds per square inch steel when c=1.

Load.	Length.	Duralumin.				Steel.				K.
		Assumed F_c.	Area.	l/ρ.	Actual f_c.	Assumed F_c.	Area.	l/ρ.	Actual f_c.	
5,000	10	28,200	0.1772	27.5	28,200	76,000	0.0657	22.1	76,100	0.960

K=ratio of weights

$$=\frac{\text{unit weight of duralumin}}{\text{unit weight of steel}}\times\frac{\text{area of duralumin}}{\text{area of steel}}$$

$$=\frac{2.80}{7.85}\,\frac{A_D}{A_S}.$$

The value of 0.960 is plotted in figure 1 against the value of l/ρ=22.1 which is the value for the steel. In figure 2, l/ρ for the steel is plotted against l/ρ for the duralumin.

APPENDIX NO. 2.

COMPUTATIONS FOR CO-3 ROOT SECTION.

The reduction in center to center distance of spar flanges through the use of large duralumin tubes instead of steel tubes is well shown in figure 6. The design moments are for the root section of the first set of Gottingen wings designed for the CO-3. Below are given the design stresses and sizes:

GENERAL DATA.

Available center height........15.55 inches.
Moment (high incidence)......1,010,000 inch-pounds.
Moment (reversed flight)........493,000 inch-pounds.
Panel length....................24 inches.

90,000 lbs. steel.		30,000 lbs. duralumin.	K.
c. to c.	13.67 in.	12.15 in.	
Upper chord:			
Stress...............	−73,200#	−83,200#	
Size...............	2″×5/32	4″×1/4	
Area...............	0.905	2.95	1.16
Lower chord:			
Stress...............	[1]+62,200#	−42,000#	
Size...............	1¾″×1/8	3″×5/32	
Area...............	[1] 0.638	1.396	[1] 0.78

[1] It will be noted that the lower chord of the steel spar was limited by tension instead of by compression. Duralumin, by reason of a high tensile strength as compared with its compressive strength is able to give lighter weight. In this case the logical procedure would be the use of a steel compression flange, with a duralumin tension flange. This type of construction is being tried out in the wing spars of the CO-1, an airplane of the same type and weight as the CO-3. This superiority of duralumin over steel in tension does not disappear until steel stronger than 155,000 pounds in tension is used, so that it appears that for most members in which tension governs, duralumin will give the lighter design.

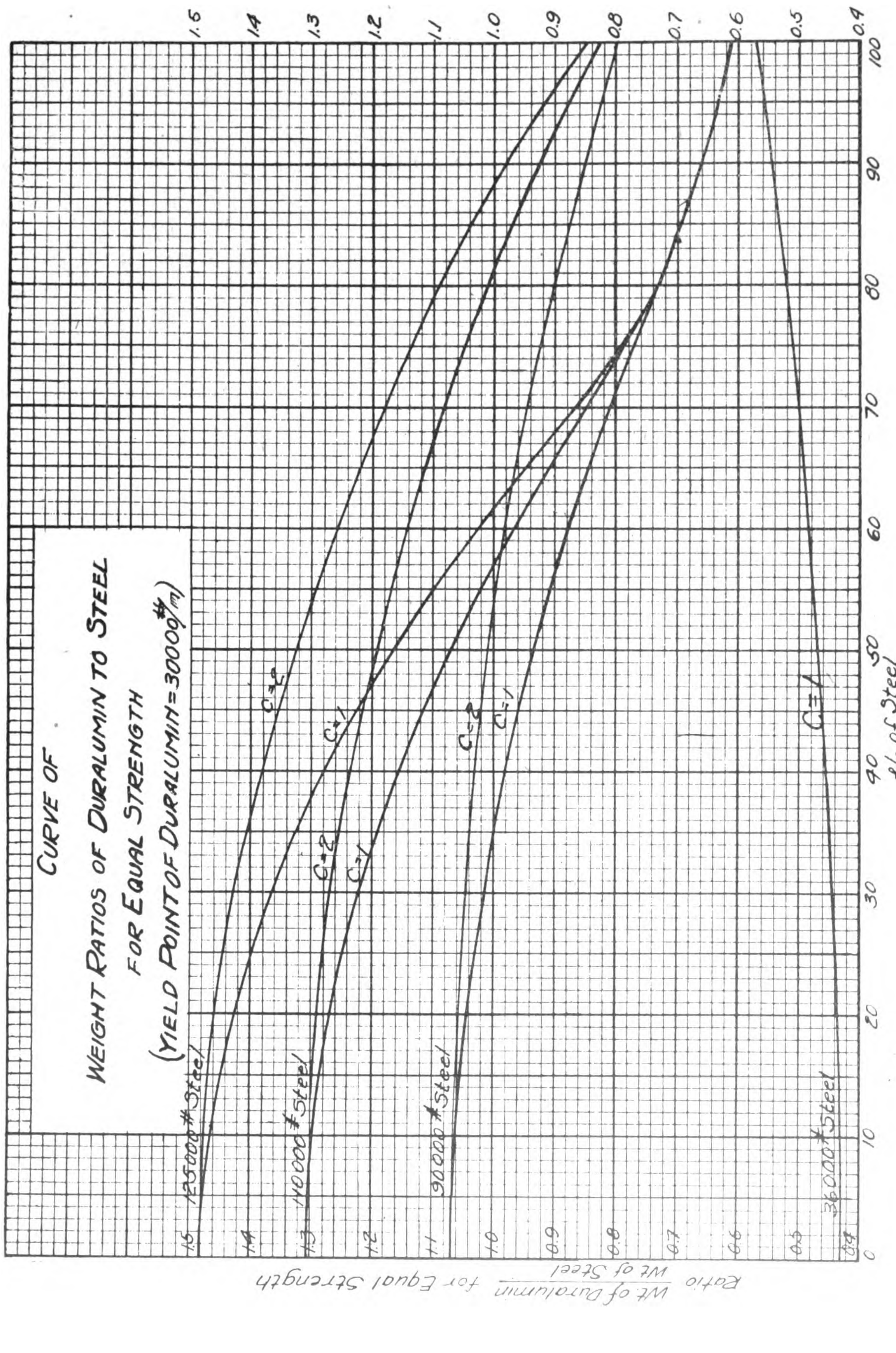

CURVE OF
WEIGHT RATIOS OF DURALUMIN TO STEEL
FOR EQUAL STRENGTH
(YIELD POINT OF DURALUMIN = 30000#/□")
125000# Steel
110000# Steel
90000# Steel
36000# Steel
C=2
C=1
C=4
l/ρ of Steel
Ratio Wt of Duralumin / Wt of Steel for Equal Strength
0
10
20
30
40
50
60
70
80
90
100
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

FIG. 1.

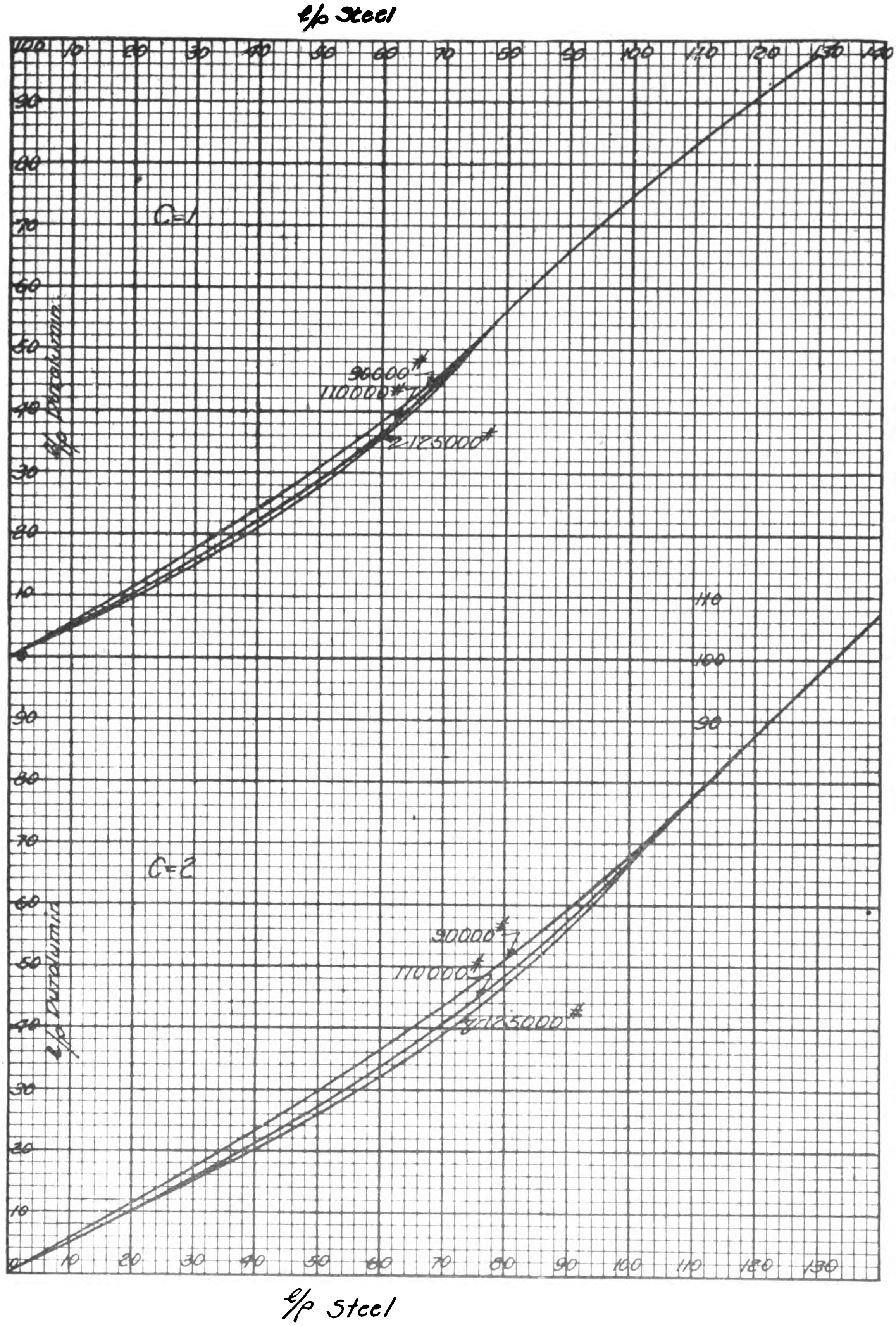

l/p Steel
C=1
90000#
110000#
125000#
l/p Duralumin
C=2
90000#
110000#
125000#
l/p Duralumin
l/p Steel

FIG. 2.

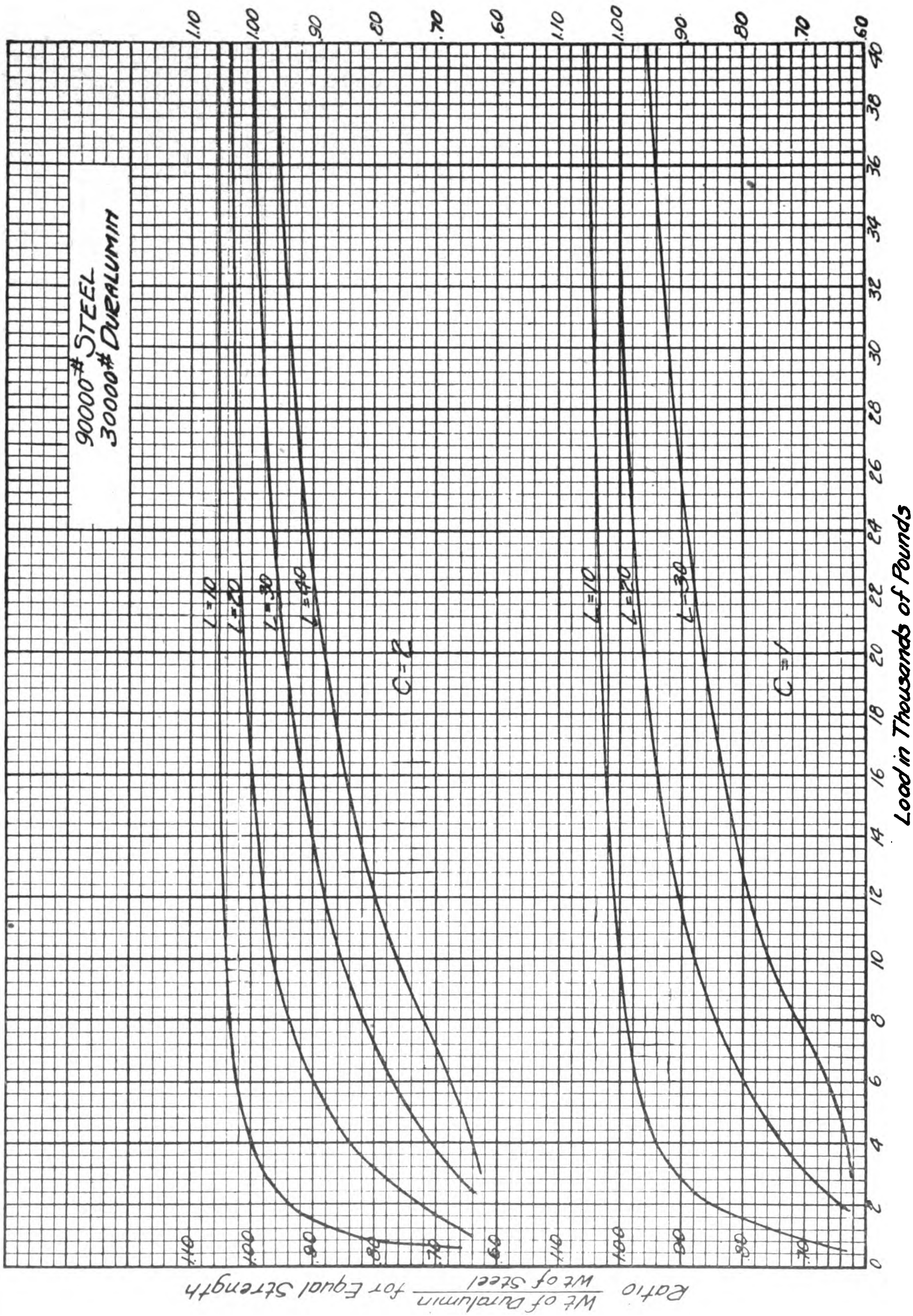

90000# STEEL
30000# DURALUMIN
L=10
L=20
L=30
L=40
C=2
C=1
Load in Thousands of Pounds
Ratio $\frac{\text{Wt of Duralumin}}{\text{Wt of Steel}}$ for Equal Strength

FIG. 3.

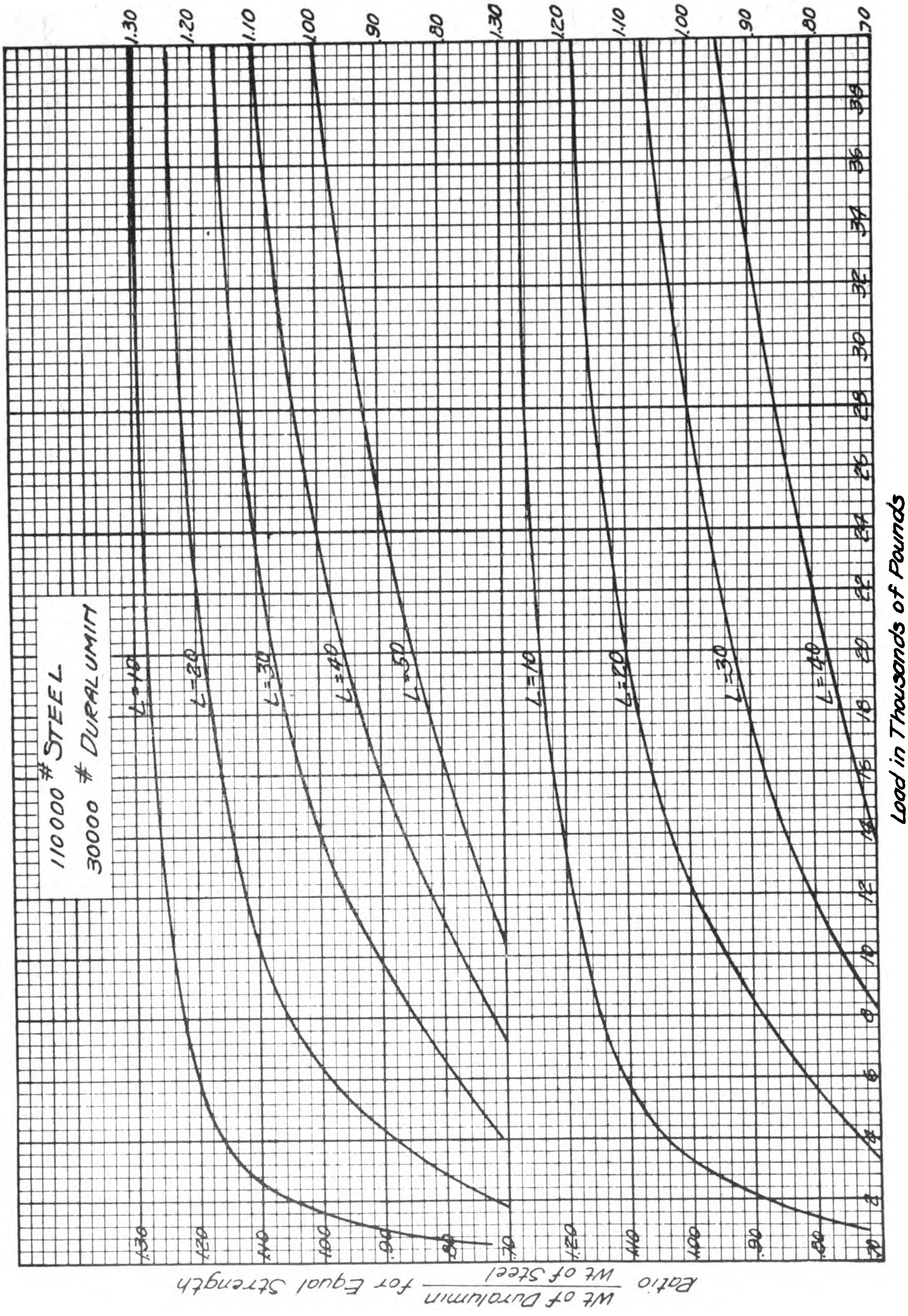

110000 # STEEL
30000 # DURALUMIN
L=10
L=20
L=30
L=40
L=50
L=10
L=20
L=30
L=40
1.30
1.20
1.10
1.00
.90
.80
.70
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
Load in Thousands of Pounds
Ratio Wt of Duralumin / Wt of Steel for Equal Strength

FIG. 4.

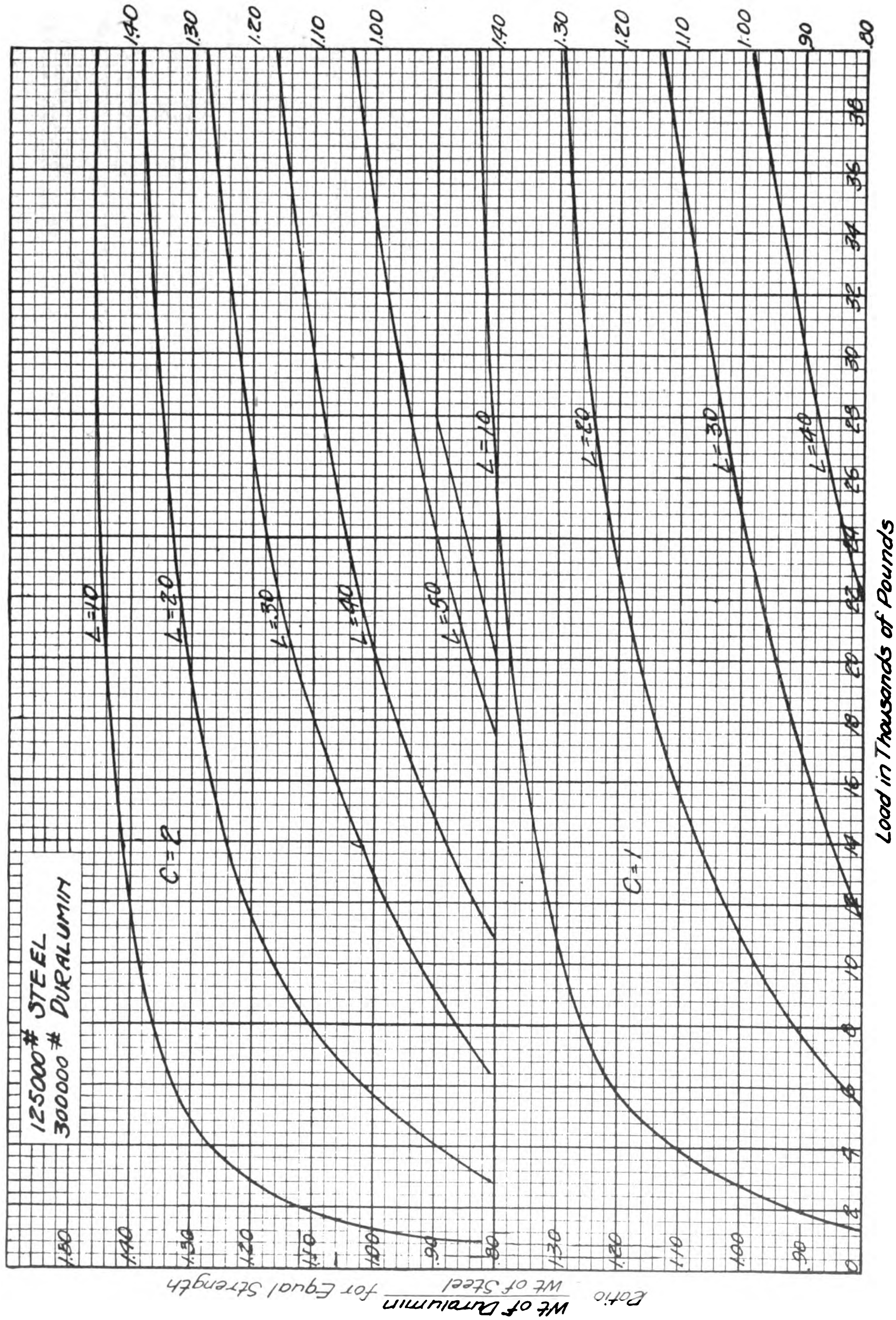
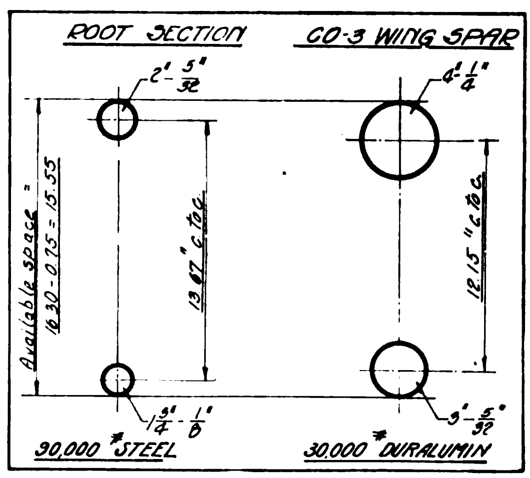

125000 # STEEL
300000 # DURALUMIN
C=2
C=1
L=10
L=20
L=30
L=40
L=50
Load in Thousands of Pounds
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
Ratio Wt of Duralumin / Wt of Steel for Equal Strength
1.40 1.30 1.20 1.10 1.00 .90 .80

FIG. 5.



ROOT SECTION
CO-3 WING SPAR
2'-5/32"
4'-1/4"
Available space "
16.30 - 0.75 = 15.55
13.67" C to C
12.15" C to C
1 3/4' - 1/8"
3'-5/32"
30,000 # STEEL
30,000 # DURALUMIN

FIG. 6.

FOR OFFICIAL USE ONLY
File D 52.1/U.S.B. 1.A/5 McCOOK FIELD REPORT, SERIAL No. 1815

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV May 1, 1922 No. 338

REPORT OF STATIC TEST OF XB-1-A FUSELAGE

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
January 4, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT OF STATIC TEST OF XB-1-A FUSELAGE.

OBJECT.

The object of this test was to determine the strength of an XB-1-A fuselage which had seen 83 hours 25 minutes service in the air and been subjected to weather conditions for 1 year 4 months and 4 days from the time of assembly until the airplane was condemned. The time of service was from July 1, 1919, to November 4, 1920.

DATE AND PLACE.

The test was conducted February 23, 1921, at McCook Field, Dayton, Ohio.

WITNESSES.

Maj. E. L. Napier.	Mr. W. E. Savage.
Lieut. E. W. Dichman.	Mr. D. B. Weaver.

SUMMARY.

The required load factor for a fuselage of this type is 7. At a load factor of $3\frac{1}{2}$ the veneer skin buckled between points C and D. At a load factor of 5.5 the veneer skin cracked open at the rear supports in the jig. At load factors of 6.5 and 7, respectively, the bottom of the fuselage buckled between No. 4 and No. 5 bulkheads back of the rear landing-gear fittings.

FUSELAGE.

DESCRIPTION.

This fuselage was built by J. C. Widman & Co., of Detroit, Mich. The overall dimensions and the general design were the same as in the other XB-1-A fuselages tested.

Figure 1 shows plan and side views of the fuselage.

The longerons of this fuselage were of solid gray elm, while the bulkheads and skin were laminated.

The laminations of the bulkheads alternate with elm and birch, with a core of either elm, poplar, or birch.

Figure 2 is a drawing of bulkhead No. 7.

The thickness and plies are as tabulated below:

Bulkhead number:

1, $\frac{7}{8}$ inch thick, 13 ply, $12\frac{1}{16}$ inch, with $\frac{1}{8}$-inch core.
2, $\frac{7}{8}$ inch thick, 13 ply, $12\frac{1}{16}$ inch, with $\frac{1}{8}$-inch core.
3, $\frac{7}{8}$ inch thick, 13 ply, $12\frac{1}{16}$ inch, with $\frac{1}{8}$-inch core.
4, $\frac{13}{16}$ inch thick, 13 ply, $13\frac{1}{16}$ inch.
5, $\frac{9}{16}$ inch thick, 9 ply, $9\frac{1}{16}$ inch.
6, $\frac{13}{16}$ inch thick, 13 ply, $13\frac{1}{16}$ inch.
7, $\frac{3}{4}$ inch thick, 12 ply, $10\frac{1}{16}$ inch, with $\frac{1}{8}$-inch core.
8, $\frac{1}{2}$ inch thick, 7 ply, $6\frac{1}{16}$ inch, with $\frac{1}{8}$-inch core.
9, $\frac{9}{32}$ inch thick, 9 ply, $9\frac{1}{32}$ inch.

All remaining bulkheads were the same as No. 9.

Bulkheads 4, 6, 7, and 8 were reinforced in thickness where fastened to longerons and other members.

The gluing area for attaching the skin to the bulkheads from No. 8, inclusive, to the rear was increased by adding a strip $\frac{1}{4}$ inch thick by $\frac{1}{2}$ inch wide to rear side. The sections of the skin were joined together by glued scarf joints and $\frac{1}{2}$-inch No. 4 flathead brass screws spaced 2 inches center to center.

The total weight of this fuselage was 210 pounds.

The condition of the fuselage when received for test was as follows:

The paint on the engine bearers was blistered with heat as seen in figure 5.

No. 3 bulkhead was pulled loose from the longerons on the lower right side.

No. 3 bulkhead was pulled away from the plywood covering on both sides and bottom, due to shocks received in landing.

The nails were pulled on No. 3 bulkhead on the right side, as shown in figure 6.

The plywood skin was buckled on the left side, as shown in figure 7.

All bulkheads from the front of the fuselage as far back as the rear of the gunner's cockpit were pulled loose from the longerons.

The whole bottom of the fuselage was covered with oil.

Figure 8 shows the condition of the bottom of the fuselage.

PROCEDURE FOR TEST.

The fuselage was mounted in a jig and supported by the wing fittings.

The loading was distributed and applied as indicated in the loading schedule in figure 3.

The tail load was carried by a platform suspended on a cable which transferred the load to the fuselage proper.

After each increment of the load had been put on, the jacks under this platform were released, so as to allow the load to act on the rear part of the fuselage structure.

RESULTS.

The deflections in inches and the tabulated results may be seen in figure 4.

At a load factor of 3.5 the veneer skin buckled at a point just to the rear of the rear wing fittings.

When a factor of 5.5 was reached the veneer cracked on both sides at the rear wing fittings.

At a load factor of 6.5 and 7 the veneer skin buckled on the bottom between bulkheads 4 and 5 back of last landing gear fittings.

Complete failure occurred at a load factor of 7.5.

Figure 9 is a photo of the failure.

DISCUSSION.

All the other tests on the XB-1-A fuselage were made on new specimens, and the failures occurred at factors as tabulated below:

No. 1—Davies-Putnam fuselage (Bristol) XB-1-A.—Tested July 29, 1918; failed at a load factor of 7.5.

No. 2—Davies-Putnam fuselage (Bristol) XB-1-A.—Tested July 30, 1918; failed at a load of 7.5.

No. 3—Davies-Putnam fuselage (Bristol) XB-1-A.—Tested August 7, 1918; failed at a load factor of 7.

No. 1—J. C. Widman & Co. fuselage (Bristol) XB-1-A.—Tested July 31, 1918; failed at a load factor of 7.

The fuselage mentioned in this test had 1 year 4 months and 4 days' service and supported a loading equivalent to a load factor of 7.

It required a load factor of 7.5 to bring about a complete failure.

CONCLUSION.

The second J. C. Widman & Co. XB-1-A fuselage was entirely satisfactory structurally.

Since this fuselage had over 1½ years' service without any indications of weakness, it is apparent that the life of the fuselage is much longer than this. With good care there is every reason to suppose that the life of this particular fuselage will be about 3 or 4 years.

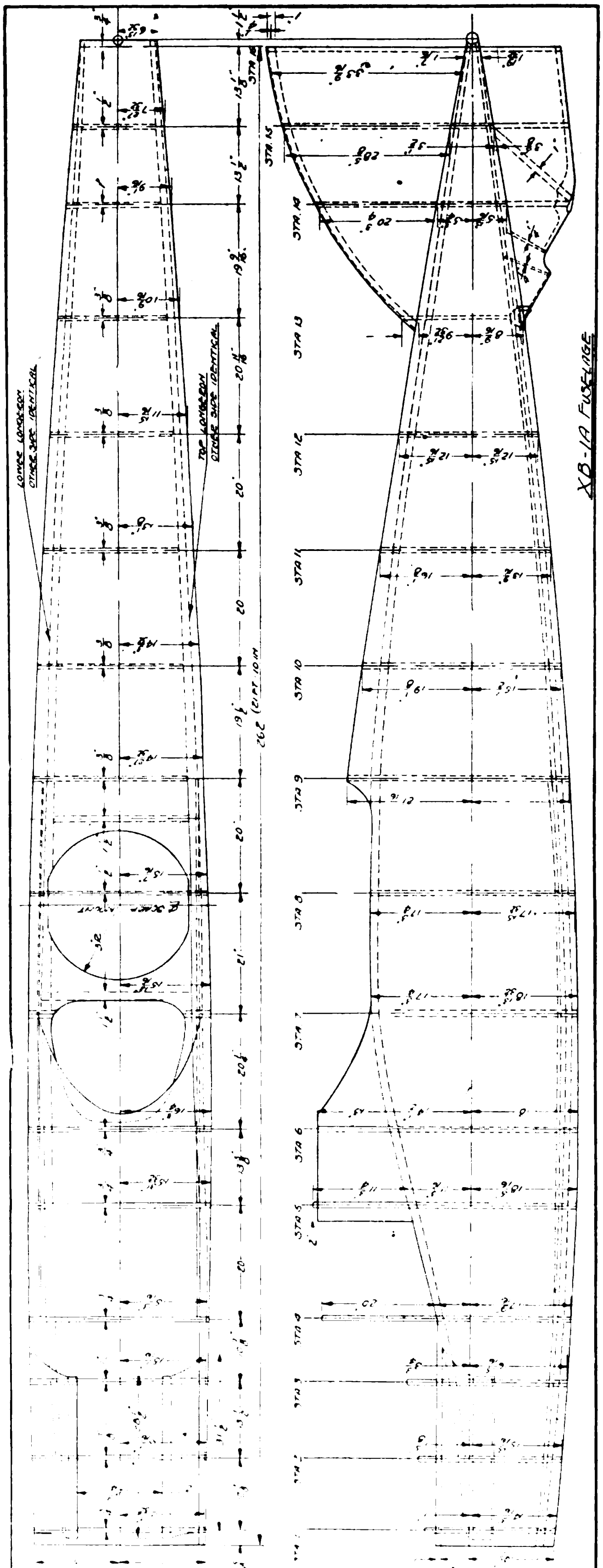
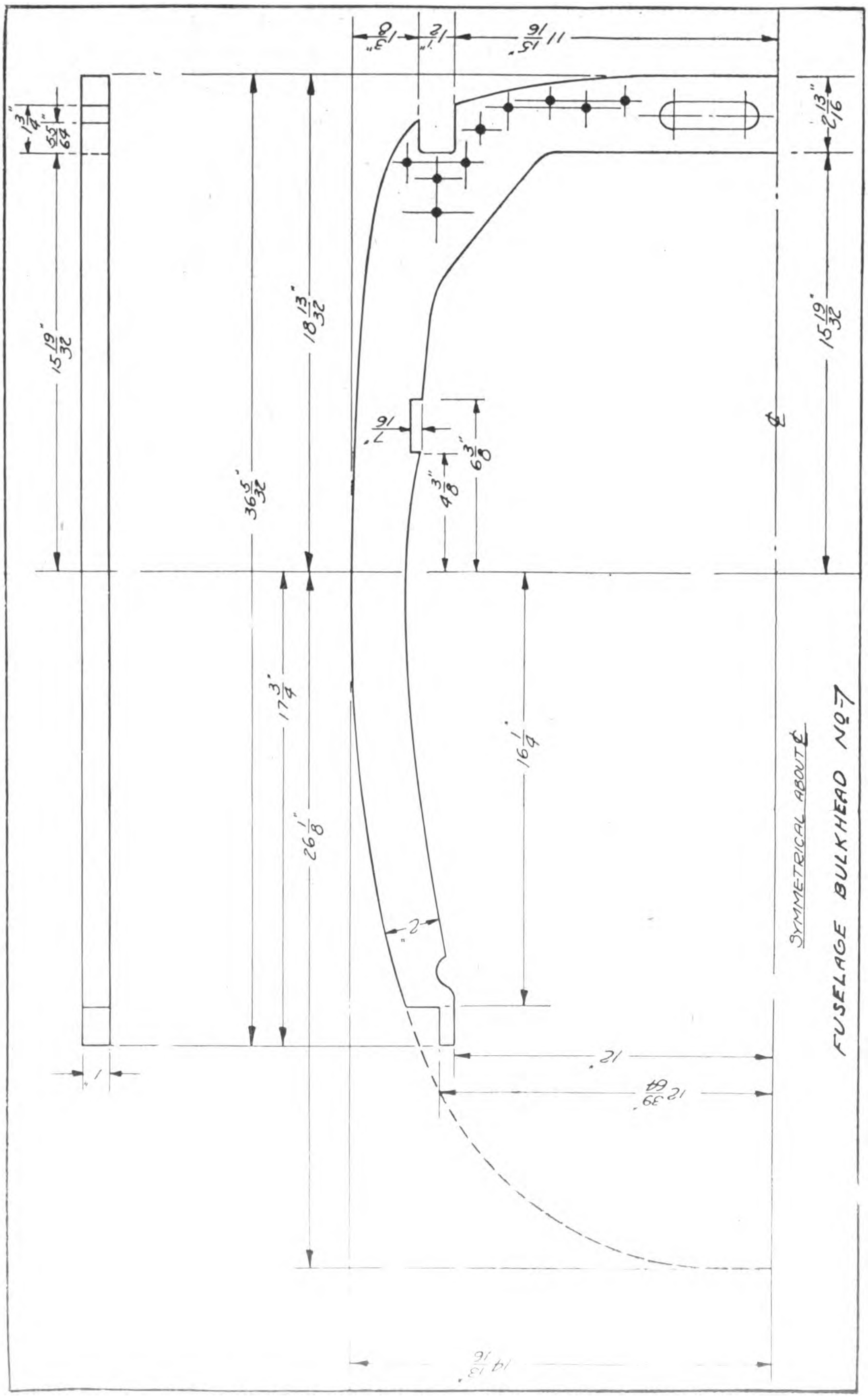
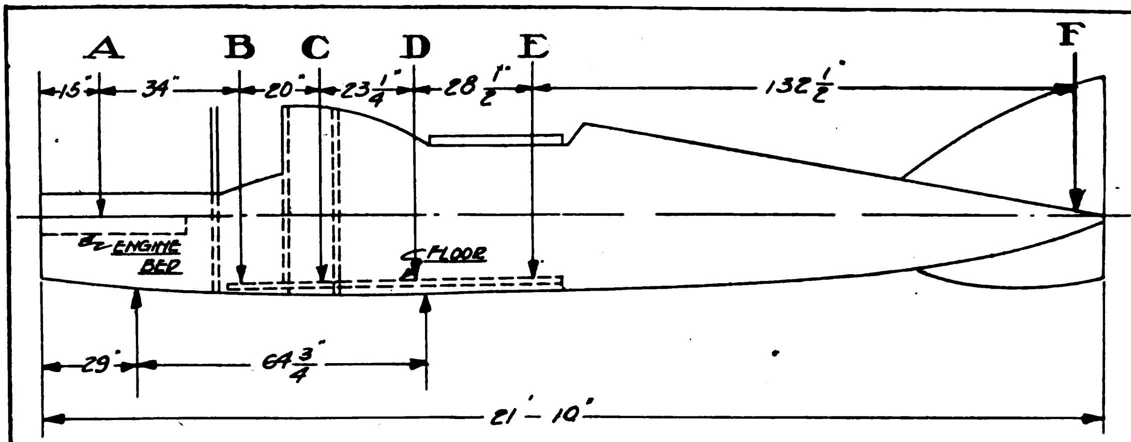


FIG. 1.



FUSELAGE BULKHEAD NO-7
SYMMETRICAL ABOUT ℄
℄
$36\frac{5}{32}$"
$18\frac{13}{32}$"
$17\frac{3}{4}$"
$26\frac{1}{8}$"
$15\frac{19}{32}$"
$16\frac{1}{4}$"
$6\frac{3}{8}$"
$4\frac{3}{8}$"
$2\frac{13}{16}$"
$1\frac{3}{4}$"
$\frac{55}{64}$"
$11\frac{15}{16}$"
$14\frac{13}{16}$"
$12\frac{39}{64}$"
12"
2"
1"

FIG. 2

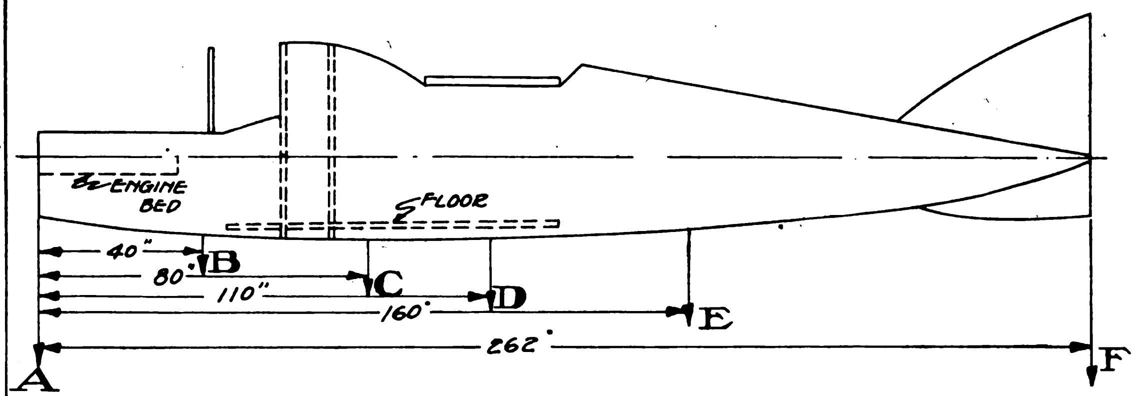


FUSELAGE LOADING SCHEDULE

LOAD NO	DYNAMIC FACTOR	TAIL LOAD LBS. PER SQ. FT.	LOAD IN LBS. AT						TOTAL LOAD ON FUSELAGE
			A	B	C	D	E	F	
1	2	10	1660	1356	280	560	640	604	5098
2	2.5	12.5	2075	1695	350	700	800	755	6373
3	3	15	2490	2034	420	840	960	906	7648
4	3.5	17.5	2905	2373	490	980	1120	1057	8923
5	4	20	3320	2712	560	1120	1280	1208	10,198
6	4.5	22.5	3735	3051	630	1260	1440	1362	11,473
7	5	25	4150	3390	700	1400	1600	1510	12,748
8	5.5	27.5	4565	3729	770	1540	1760	1661	14,023
9	6	30	4980	4068	840	1680	1920	1812	15,298
10	6.5	32.6	5395	4407	910	1820	2080	1963	16,573
11	7	35.0	5810	4746	980	1960	2240	2114	17,848
12	7.5	37.5	6225	5085	1050	2100	2400	2265	19,125

XB-1A FUSELAGE

FIG. 3.



LOAD FACTOR	DEFLECTION IN INCHES AT						REMARKS
	A	B	C	D	E	F	
2	1.6	1.4	.8	.2	-.4	-.6	
2.5	1.7	1.5	.9	.3	-.2	-.5	
3	1.8	1.6	1.0	.5	0	-.2	
3.5	1.8	1.7	1.0	.5	+.1	.2	BUCKLE IN VENEER TO REAR OF REAR WING FITTING.
4	1.9	1.7	1.1	.7	.5	.5	
4.5	1.9	1.9	1.2	.9	.6	.9	
5	2.0	1.9	1.3	1.0	.8	1.4	
5.5	2.0	1.9	1.4	1.2	1.1	1.7	VENEER CRACKED OPEN BY BUCKLING AT REAR WING FITTINGS.
6	2.1	2.0	1.4	1.4	1.3	2.2	
6.5							BUCKLING IN BOTTOM BETWEEN NO. 4 & 5 BULKHEADS, JUST BACK OF
7							LANDING GEAR FITTING.
7.5							FAILURE

X8-1A FUSELAGE

FIG. 4.

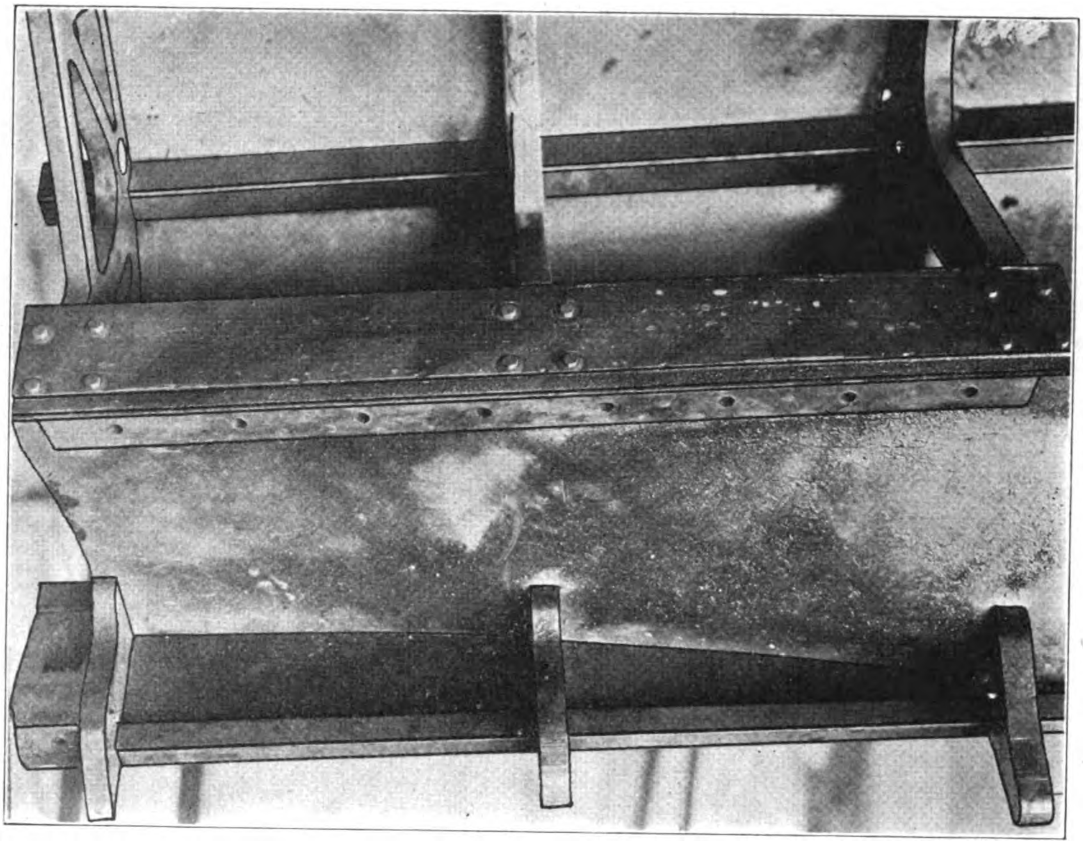


FIG. 5.

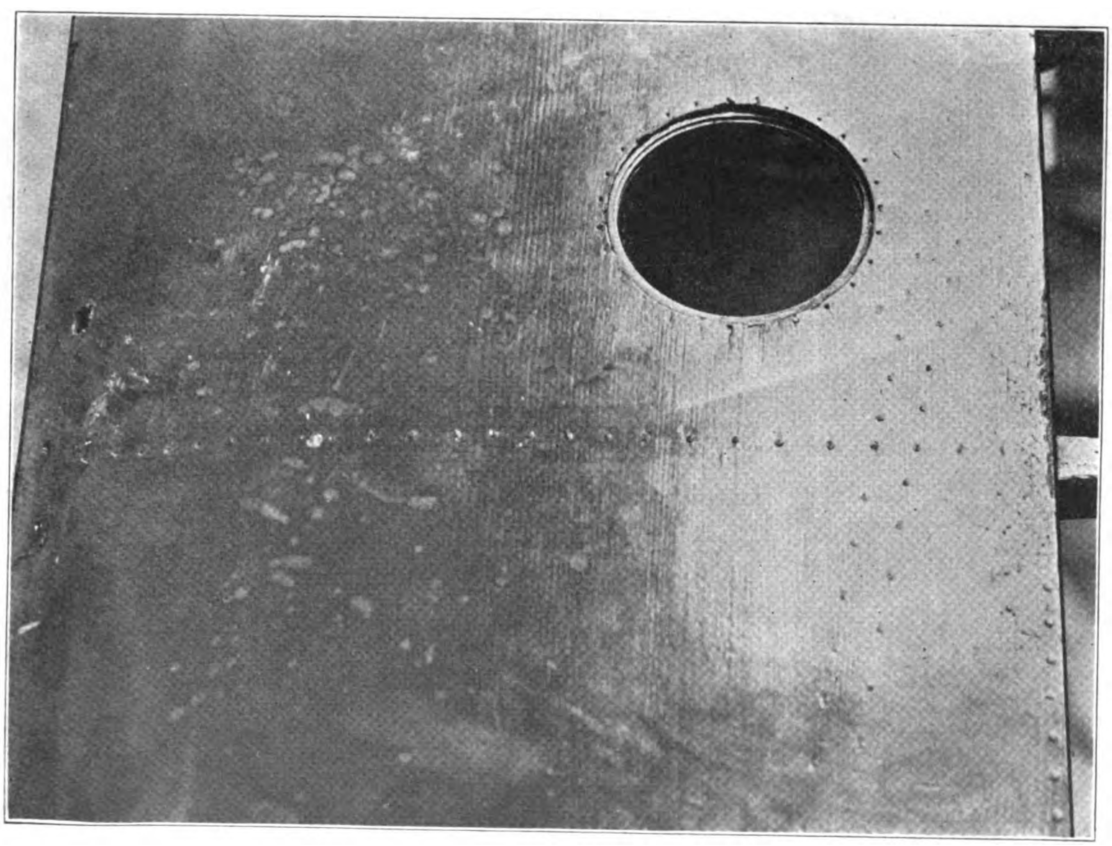


FIG. 6.

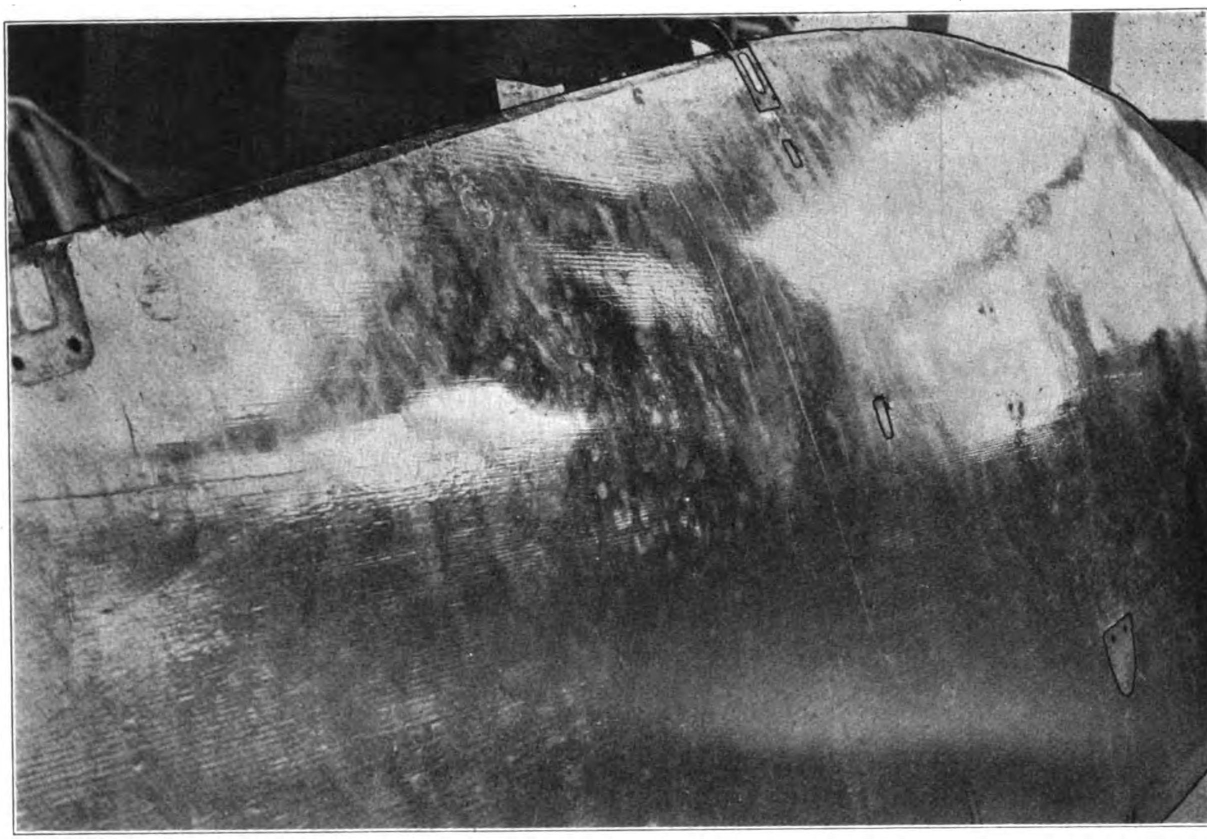


FIG. 7.

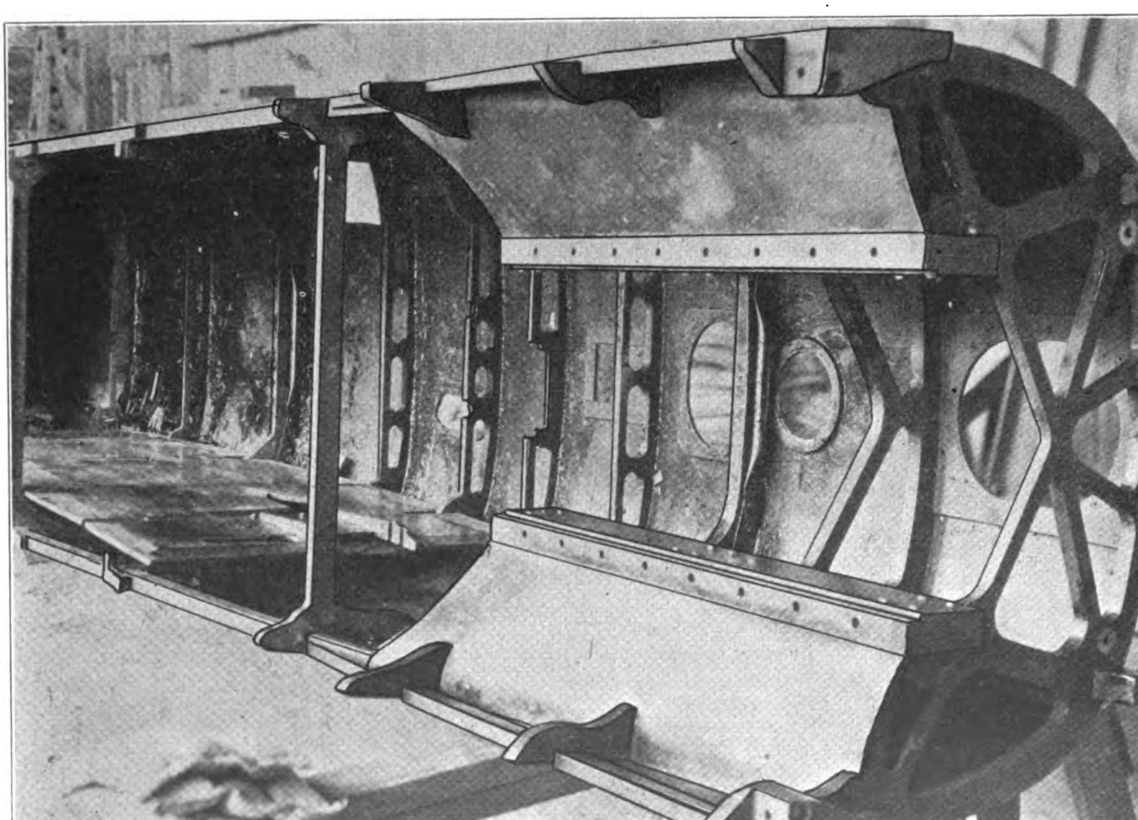


FIG. 8.

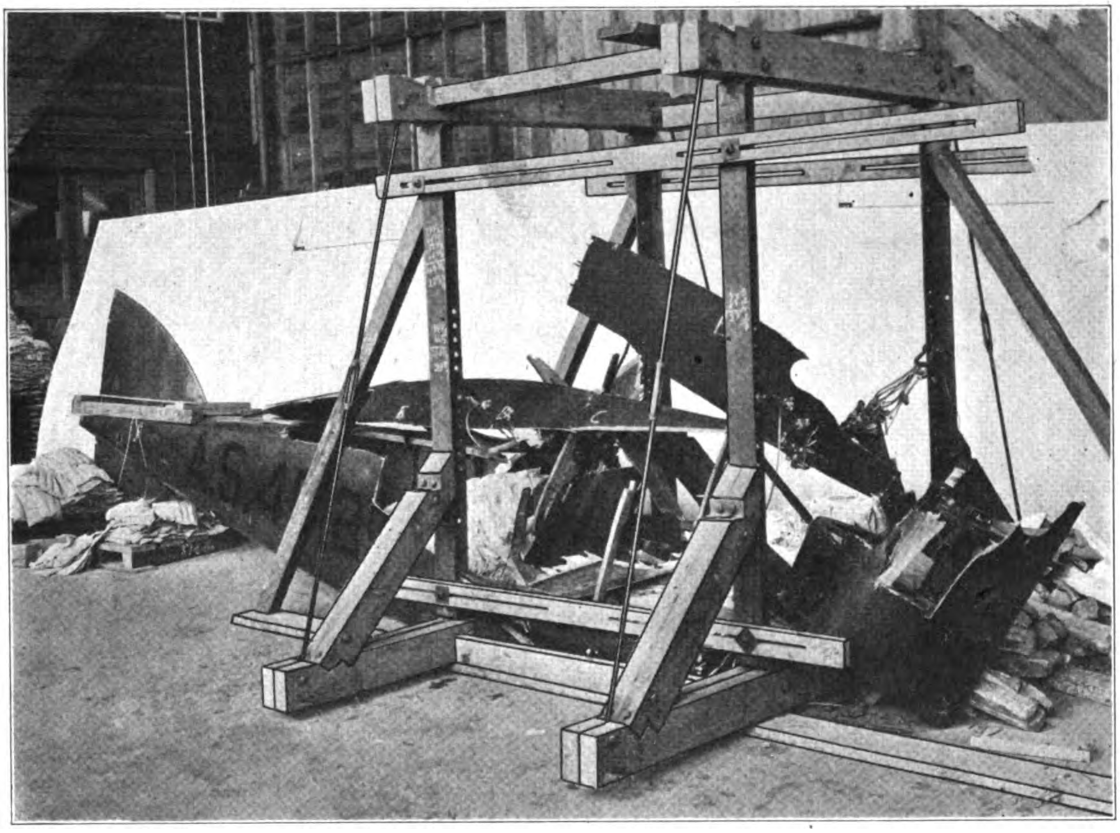


Fig. 9.

File D 13.3/Thermometers/10 *McCOOK FIELD REPORT, SERIAL No. 1824*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV May 1, 1922 No. 339

TEMPERATURE EFFECT ON CAPILLARIES OF LIQUID AND VAPOR PRESSURE THERMOMETERS

(EQUIPMENT SECTION TEST REPORT)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
January 17, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

TEMPERATURE EFFECT ON CAPILLARIES OF LIQUID AND VAPOR PRESSURE THERMOMETERS.

OBJECT.

The purpose of this test was to determine the temperature effect on capillaries of vapor and liquid pressure thermometers.

CONCLUSIONS.

Vapor pressure thermometers are not appreciably affected by a change of capillary temperature.

Liquid pressure thermometers are subject to large errors when a relatively large temperature difference exists between the bulbs and capillaries.

PROCEDURE.

The apparatus was set up as shown in figure 2. The bulbs were heated in a water bath by increments of 5° C. to about 80° C., while the capillaries were allowed to remain at room temperature. The capillaries (10-inch segment) were then heated in a paraffin bath by 5° C. increments to 240° C., while the bulbs were kept at a constant temperature of about 80° C. The data as indicated in the following table were observed and recorded at each temperature change.

DISCUSSION.

Figure 1 shows plainly the characteristics of the two types of thermometers. If the entire length of their capillaries (instead of 10-inch central segment) had been heated, the error in the case of the liquid-filled thermometer would have been increased several times, but that of the vapor-filled thermometer would hardly have been affected.

The Boyce liquid-filled thermometer shows an unusually large error of 11¾° C. for a temperature difference of 158° C. between its bulb and capillary. The direct linear expansion of the inclosed liquid is responsible for this error. Liquid-filled thermometers are not appreciably affected by a change of external pressure on account of the high internal pressure of the liquid (about 800 pounds per square inch). The scales of these instruments are open and uniform and they are reliable at all temperatures within their range, provided there is no great temperature difference between the bulbs and capillaries.

The national gage vapor-filled thermometer was not appreciably affected by a change of temperature of its capillary. The error was at no time greater than ±1½° C., although the temperature difference between its bulb and capillary was raised to 158° C. The coefficient of expansion of a gas is so small that no noticeable change in gage reading was indicated.

The vapor pressure of a liquid increases very rapidly with an increase in temperature. For this reason the scale is closed at low temperatures and open at high temperatures. Vapor pressure thermometers are seriously affected by a change of external pressure of the vapor.

DATA.

Barometer .... 29.3″
Room and gage temperature .... 24° C.
12-foot capillaries, 10-inch central segment heated.

Reading.	Type "D," No. 1892-N, National gage thermometer reading, ° C.	Error.	Model "E," No. 32381, Boyce thermometer reading, ° C.	Error.	Temperature of bulbs, ° C. std.	Temperature of capillaries, ° C. std.	Temperature difference, bulbs and capillaries, ° C.
1	17	+3½	13	−1½	13½	21	....
2	22½	+1	22	+½	21½	21½	0
3	23	−2	25¼	+¼	25	21½	− [1] 3½
4	25	−5	31	+1	30	21½	−8½
5	32	−3	35	0	35	21½	−13½
6	37	−3	40	0	40	21½	−18½
7	43	−2	45	0	45	21½	−23½
8	48	−2	50	0	50	21½	−28½
9	54	−1	55	0	55	22	−33
10	58¼	−1¾	60	0	60	22	−38
11	63½	−1½	65½	+½	65	22	−43
12	69½	−½	71	+1	70	22	−48
13	74½	−½	76	+1	75	22	−53
14	79½	−½	81½	+1½	80	22	−58
15	84	−1	86½	+1½	85	22	−63
16	88½	−1½	91½	+1½	90	22	−68
17	93½	−1½	96½	+1½	95	22	− [2] 73
18	81½	+1	82	+1½	80½	25	−55½
19	80	+½	81¼	+1¾	79½	30	−49½
20	78½	−¼	80	+1¼	78¾	35	−43¾
21	79	−½	81	+1½	79½	40	−39½
22	79	−½	81¼	+1¾	79½	45	−34½
23	79	−½	81½	+2	79½	50	−29½
24	79	−½	81½	+2	79½	55	−24½
25	79	−½	82	+2½	79½	60	−19½
26	79	−½	82	+2½	79½	65	−14½
27	79	−½	82	+2½	79½	70	−9½
28	79½	−½	82½	+2½	80	75	−5
29	80	−¼	82¾	+2½	80¼	80	−¼
30	81	+¾	83	+2¾	80¼	85	+4¾
31	81	+½	83½	+3	80½	90	+9½
32	81	+¼	84	+3¼	80¾	95	+14¼
33	81	+¼	84½	+3¾	80¾	99	+ [3] 18¼
34	80½	0	84	+3½	80½	100	+19½
35	80	0	83	+3	80	105	+25
36	79	−½	82¾	+3¼	79½	110	+30½
37	78½	−¾	82½	+3¼	79¼	115	+35¾
38	79¾	−¼	82¾	+3¾	80	120	+40
39	80¾	0	84½	+3¾	80¾	125	+44¼
40	80½	0	84¾	+4¼	80½	130	+49½
41	80	−¼	84¼	+4	80¼	135	+54¾
42	79	−½	84	+4½	79½	140	+60½
43	78½	−1½	83¼	+4¼	80	145	+65
44	78	−1¼	83½	+4¼	79¼	150	+70¾
45	78	−1½	84	+4½	79½	155	+ [4] 75½
46	78	−1	84	+5	79	160	+81
47	79½	−¾	85	+4¾	80¼	165	+84¾
48	79	−1	84½	+4½	80	170	+90
49	79½	−¾	85	+4¾	80¼	175	+94¾
50	79¾	−½	85½	+5¼	80¼	180	+99¾
51	80	−¾	86	+5¼	80¾	185	+104¼
52	80½	−1	86¾	+5¾	81	190	+109
53	81	−½	87½	+6	81½	195	+113½
54	81¾	−¼	88	+6	82	200	+118
55	81¾	−¼	89½	+7½	82	205	+123
56	80½	−¼	90	+9¼	80¾	210	+129¼
57	80¼	−¼	91	+10½	80½	215	+134½
58	80½	−¼	91	+10¼	80¾	220	+139¼
59	80¾	−¼	91¾	+10¾	81	225	+144
60	81	−¼	92	+10¾	81¼	230	+148¾
61	81	−½	92¾	+11¼	81½	235	+ [5] 153½
62	81½	−¼	93½	+11¾	81¾	240	+158¼

[1] Started to vibrate gages.
[2] Began heating capillaries.
[3] Bath changed to paraffin. Room temperature, 22° C.
[4] Test renewed next day. Room temperature, 22° C.
[5] Paraffin ignited at about 243° C., flash point.

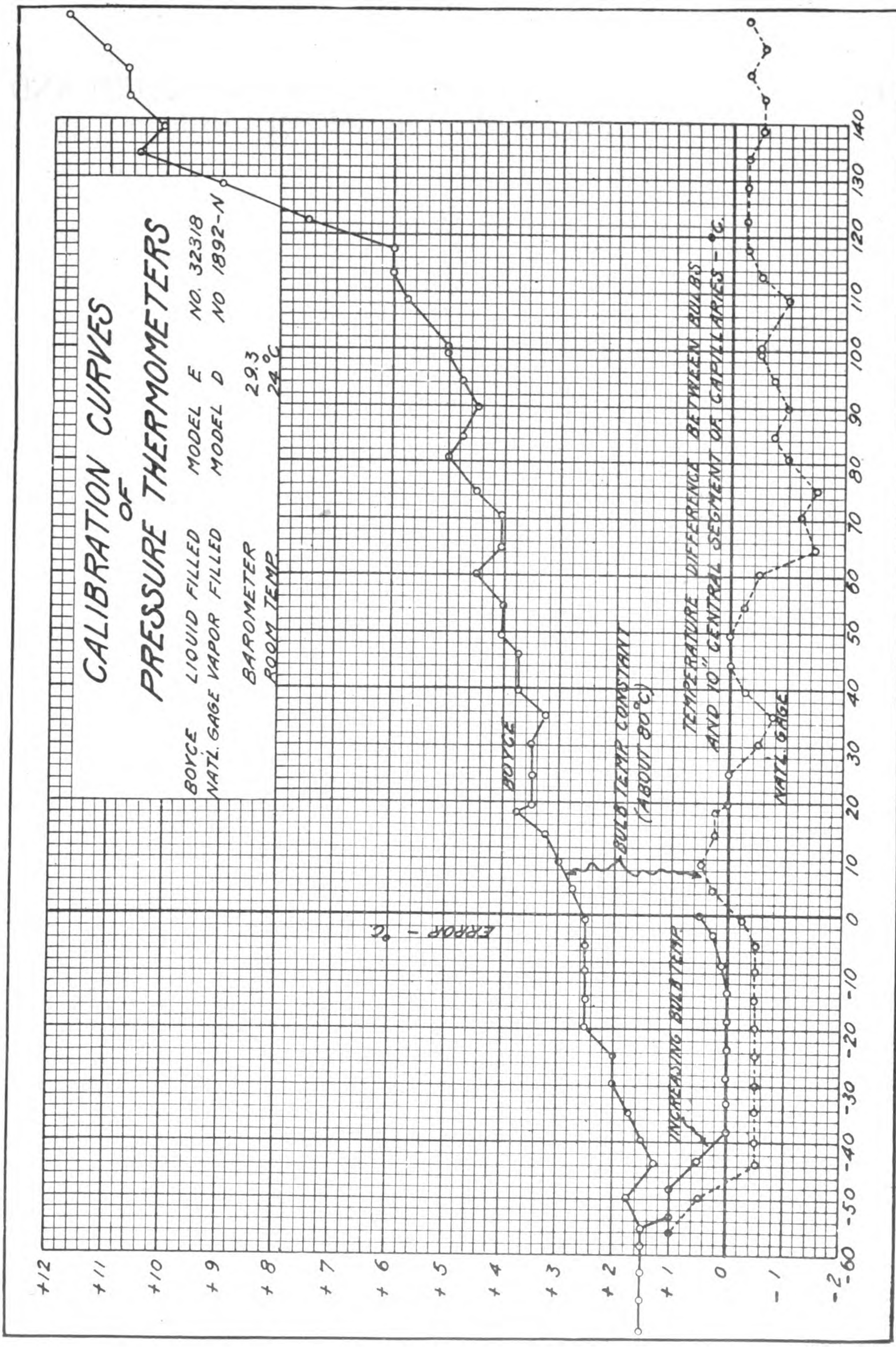
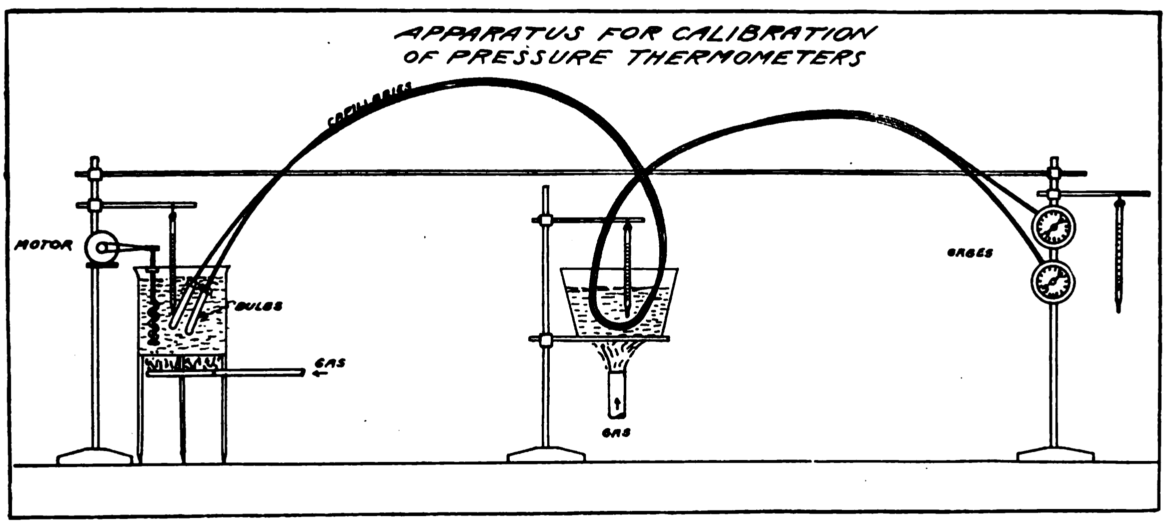

CALIBRATION CURVES
OF
PRESSURE THERMOMETERS
BOYCE LIQUID FILLED MODEL E NO. 32318
NATL. GAGE VAPOR FILLED MODEL D NO 1892-N
BAROMETER 29.3
ROOM TEMP 24°C
BOYCE
BULB TEMP CONSTANT
(ABOUT 80°C)
TEMPERATURE DIFFERENCE BETWEEN BULBS
AND 10" CENTRAL SEGMENT OF CAPILLARIES - °C.
NATL. GAGE
INCREASING BULB TEMP.
ERROR - °C.
-60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
+12 +11 +10 +9 +8 +7 +6 +5 +4 +3 +2 +1 0 -1 -2

FIG. 1.



APPARATUS FOR CALIBRATION
OF PRESSURE THERMOMETERS
CAPILLARIES
MOTOR
BULBS
GAS
GAS
GAGES

FIG. 2.

O

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV May 1, 1922 No. 340

STATISTICS COMPILED FROM REPORTS ON CRASHES IN THE U. S. ARMY AIR SERVICE DURING THE CALENDAR YEARS 1918-1921, INCLUSIVE, AND RESULTS OF PHYSICAL EXAMINATIONS FOR FLYING DURING THE CALENDAR YEARS 1920 AND 1921

COMPILED BY THE MEDICAL SECTION
OF THE AIR SERVICE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
5 CENTS PER COPY

AIRPLANE CRASHES, 1918 AND 1919, IN THE UNITED STATES ARMY AIR SERVICE.

A BRIEF SUMMARY OF 1,250[1] SPECIAL CRASH REPORTS.

(Prepared in the Office of the Chief Surgeon, Air Service.)

A total of 1,250 reports of crashes were received from the various flying fields, covering a period from the begining of the war up to January 1, 1920, on special crash report blanks sent out from the Office of the Chief Surgeon, Air Service.

While these crash returns are incomplete, owing to the fact that many fields did not report all of their crashes, it is thought that the 1,250 reports received are representative and will show valuable data bearing on the causes leading up to the crashes, injuries suffered by pilot, extent of damage resulting to airplane, and other information of interest.

Statistics of these crashes have been compiled in considerable detail but only a brief summary will be given here.

Segregating the 1,250 crashes according to the nature of the crash, it will be seen that bad landing was responsible for a little more than 45 per cent of the total accidents reported, lacking but a little of causing four times as many crashes as any other one cause.

A brief summary of all crashes, listed according to the nature of the crash, is given below:

Nature of crash.	Number.	Per cent of total.
Bad landing	563	45.04
All spins	160	12.80
Collision (other than with ship)	120	9.60
Stall (engine trouble)	97	7.76
Side slip	64	5.12
Burning of plane	58	4.64
Taxing (collision on ground)	49	3.92
Nose dives	46	3.68
Collision (in air with ship)	45	3.60
Unknown	9	.72
Total	1,250	100.00

Taking up the extent of injuries to the pilot as a result of crashes, we find that a little more than one crash out of 10 proved fatal. The nature of crash resulting in the highest percentages of fatalities were collision (in air with ship), nose dives, and all spins, with percentages of 46.67, 30.43, and 27.50 of fatalities, respectively. A brief summary is given below:

Extent of injuries.	Number of crashes.	Per cent of total.
Fatal	135	10.80
Injured	303	24.24
Uninjured	807	64.56
Unknown	5	.40
Total	1,250	100.00

In assigning a cause for the crash, many factors enter into the situation, so that unless a board is convened and forwards a formal report, very much depends upon the viewpoint of the person making out and sending in the special crash report. When no cause for the crash was given, or the cause as shown was obviously wrong, an arbitrary cause was assigned for the crash by this office in working up this data when the information at hand seemed to justify it. A summary of the crashes by cause is shown below:

Cause of crash.	Number of crashes.	Per cent of total.
Bad judgment	597	47.52
Engine trouble	263	21.04
Unavoidable	225	18.00
Inexperience	45	3.60
Body of plane	37	2.96
Vertigo	12	.96
Acute physical impairment	10	.80
Chronic physical impairment	3	.24
Unknown	61	4.88
Total	1,250	100.00

Segregating crashes, according to the period of day in which the accident occurred, shows the following:

Period of day.	Number of crashes.	Per cent of total.
From 5 a. m. to 10 a. m	313	25.04
From 10 a. m. to 3 p. m	552	44.16
From 3 p. m. to 6 p. m	255	20.40
From 6 p. m. to 5 a. m	112	8.96
Unknown	18	1.44
Total	1,250	100.00

Segregating the crashes by the age of the fliers, we find that 65 per cent occurred among aviators between 21 and 26 years of age. A summary is given below:

Age of flier.	Number of crashes.	Per cent of total.
18 to 20 years	58	4.64
21 to 23 years	437	34.96
24 to 26 years	376	30.08
27 to 30 years	220	17.60
31 to 35 years	61	4.88
36 to 40 years	12	.96
41 to 45 years	5	.40
Unknown	81	6.48
Total	1,250	100.00

In regard to the number of hours dual instruction received by the flier before the occurrence of the crash, we

[1] Statistics compiled by the Information Division, Office of the Chief of Air Service, show 2,311 airplane crashes in the United States from April 6, 1917, to January 1, 1920. Some of these were not included in this compilation because of their minor character, others because they occurred at points where it was impracticable for a flight surgeon to make an investigation.

find that 71 per cent has received from 5 to 19 hours dual instruction in the piloting of a plane prior to the occurrence of the crash reported. A summary is given below:

Hours dual instruction received.	Number of crashes.	Per cent of total.
Less than one hour's instruction	5	0.40
1 to 5 hours' instruction	66	5.28
5 to 9 hours' instruction	524	41.92
10 to 19 hours' instruction	366	29.28
20 to 29 hours' instruction	46	3.68
Over 29 hours' instruction	30	2.40
Unknown	213	17.04
Total	1,250	100.00

Experience in solo flying among aviators meeting with crashes varied from a few hours in the case of the cadet to more than a thousand with the experienced bird man. A summary shows the following:

Experience in solo flying.	Number of crashes.	Per cent of total.
Less than 25 hours' solo	259	20.72
25 to 50 hours' solo	156	12.48
50 to 100 hours' solo	202	16.16
100 to 250 hours' solo	301	24.08
250 to 500 hours' solo	136	10.88
500 to 1,000 hours' solo	45	3.60
Over 1,000 hours' solo	26	2.08
Unknown	125	10.00
Total	1,250	100.00

Taking up the question of weather conditions as bearing on the number of crashes, we find that almost 75 per cent occurred during fair weather. Unfortunately, for purposes of correlation, we have no record of the total amount of flying done under the varying weather conditions. The following table gives weather conditions prevailing at the time of occurrence of crashes reported:

Weather conditions.	Number of crashes.	Per cent of total.
Fair	920	73.60
Windy (over 15 miles)	151	12.08
Cloudy	75	6.00
Stormy	45	3.60
Foggy	40	3.20
Dark	10	.80
Unknown	9	.72
Total	1,250	100.00

Segregating the number of crashes according to the type of plane used, we find that a total of 1,092 crashes out of the 1,250 reported, occurred during the use of the Curtiss plane. Unfortunately again, we have no statistics showing comparison between the number of crashes occurring and the total hours flown by pilots using the various types of machines.

A further segregation of crashes by type of plane used, and according to the nature of the crash resulting, reveals the fact that crashes of a like nature occur relatively more frequent in one type of plane than in another. For instance, 61.64 per cent of all crashes occurring in the use of the DeHaviland are attributed to bad landing, while the percentage of crashes due to bad landings by pilots of Curtiss and "Scout" planes were but 43.98 and 31.25 per cent, respectively. In the matter of spins, 25 per cent of all accidents occurring during the use of "Scout" planes are attributed to this cause, as against but 3.49 per cent for the DeHaviland. In the stalls (engine trouble), the Curtiss plane shows the lowest percentage (7.60 per cent), and "Foreign" planes the highest (11.43 per cent).

A brief summary showing crashes by type of plane used is shown below:

Type of plane.	Number of crashes.	Per cent of total.
Curtiss	1,092	87.36
DeHaviland	86	6.88
Foreign	35	2.80
Scouts	16	1.28
All others	16	1.28
Unknown	5	.40
Total	1,250	100.00

Tabulating injuries and fatalities according to type of plane we find the Curtiss plane was used in 87.36 per cent of all crashes reported, but was responsible for only 75.78 of total fatalities. In the matter of injuries, however, it rises slightly above the relative proportion of crashes, being charged with 88.78 per cent of all injuries.

The highest fatality incidence in ratio to the number of crashes occurred in the use of "Scout" (including all scouts except foreign planes) planes, 43.75 per cent of all crashes terminating fatally to the pilot, as against 9.20 per cent for the Curtiss machine.

A brief summary of injuries by type of plane is given herewith:

Type of plane.	Killed.	Injured.	Uninjured.	Unknown.	Total.
Curtiss	105	269	669	3	1,092
De Haviland	13	19	52	2	96
Scout	7	5	4	....	16
Foreign	5	8	22	....	35
All other	5	1	10	....	16
Unknown	....	1	4	....	5
Total	135	303	807	3	1,250
Percentage	10.80	24.24	64.56	0.40	100.00

Taking up the question of age and its possible bearing on the cool judgment and resourcefulness so necesary in the case of a flier, it is interesting to note that the percentage of crashes attributed to bad judgment on the part of the pilot shows a steady decline from the young pilot of 18 or 20 to the more mature judgment of the flier of 30 to 35 years of age. In reverse ratio are the percentage of crashes listed as unavoidable, which show a percentage of only 12.08 of all crashes occurring among pilots from 18 to 20 years of age, and rises to 26.81 per cent of all crashes among pilots from 27 to 30 years of age.

Number of crashes, are percentages of total, in which the cause was shown as bad judgment or unavoidable, are given below:

Age of pilot.	Cause of crash.			
	Bad judgment.		Unavoidable.	
	Number.	Per cent of total.[1]	Number.	Per cent of total.[1]
18 to 20 years	34	58.63	7	12.08
21 to 25 years	226	51.71	70	16.02
24 to 26 years	166	44.12	67	17.91
27 to 30 years	91	41.36	59	26.81
31 to 35 years	25	40.98	14	22.95
36 to 40 years	6	50.00	....	....
41 to 45 years	3	60.00	1	20.00
Unknown	43	53.09	7	8.64
Total	594	47.52	225	18.00

[1] Percentage of total crashes chargeable against each age group.

In basing a conclusion in the preceding table that age might have a tendency to promote prudence and carefulness in a pilot, and assuming that the ranking of pilots to a large extent followed their experience and natural ability as fliers, one would expect to find the percentage of crashes due to bad judgment on the part of the pilot steadily decreasing on passing from the lower ranking officers to the higher, and the percentage of unavoidable crashes steadily increasing. How well such a conclusion is borne out is shown by the following table:

Rank of flier.	Cause of crash.			
	Bad judgment.		Unavoidable.	
	Number.	Per cent of total.[1]	Number.	Per cent of total.[1]
Enlisted personnel	14	42.43	4	12.12
Cadet	213	56.80	43	11.46
Second lieutenant	283	44.77	123	21.04
First lieutenant	38	38.00	25	25.00
Captain	11	39.29	8	28.57
Major	2	16.67	5	41.67
Lieutenant colonel	3	60.00		
Colonel	3	50.00		
Civilian instructor	4	50.00		
Unknown	23	45.10	7	13.73
Total	594	47.52	225	18.00

[1] Per cent of total crashes chargeable against each group according to rank.

Segregating all crashes by rank of fliers, gives the following figures and percentage:

Rank of flier.	Number of crashes.	Per cent of total.
Enlisted	33	2.64
Cadet	375	30.00
Second lieutenant	632	50.56
First lieutenant	100	8.00
Captain	28	2.24
Major	12	.96
Lieutenant colonel	5	.40
Colonel	6	.48
Civilian instructor	8	.64
Unknown	51	4.08
Total	1,250	100.00

Segregating the crashes according to the resulting damage to the plane, we find that a little over 43 per cent of total crashes reported resulted in a complete wreck of the machine. Spins, collision in air, nose dives, and side slips show the greatest proportion of total wreckage of plane, with the following percentages: 93, 82, 74, and 67 per cent, respectively. Of all crashes attributed to "Bad landing" 23.6 per cent resulted in a complete wreck of the machine.

A short summary of damages to plane resulting from crashes is shown below:

Damage to airplane.	Number of crashes.	Per cent of total.
Complete wreck	539	43.12
Undercarriage, propeller and wings	160	12.80
Undercarriage and propeller	125	10.00
Propeller and wings	89	7.12
Undercarriage and wings	84	6.72
Propeller	84	6.72
Undercarriage	63	5.04
Wings	57	4.56
Slight	17	1.36
Unknown	32	2.56
Total	1,250	100.00

Taking up the question of fatalities and injuries resulting from crashes it will be seen that they vary proportionately to the severity of damage to plane. In 95.56 per cent of all fatalities occurring, and in 80.86 per cent of all injuries, the plane was completely wrecked. Nearly one out of four of the crashes (23.93 per cent) resulting in a complete wreck of the machine caused a fatality, and 60 per cent of the remaining resulted in more or less serious injuries to the pilot.

A brief summary of crashes by damage to plane and resulting injury to pilot is given below:

Damage to airplane.	Fate of pilot.				
	Killed.	Injured.	Uninjured.	Unknown.	Total.
Complete wreck	129	245	163	2	539
Undercarriage, propeller and wings		21	139		160
Undercarriage and propeller	1	5	118	1	125
Propeller and wings		2	85	2	89
Undercarriage and wings	1	8	75		84
Propeller		3	81		84
Undercarriage		4	59		63
Wings	1	4	52		57
Slight		1	16		17
Unknown	3	10	19		32
Total	135	303	807	5	1,250
Percentage	10.80	24.24	64.56	0.40	100.00

A distribution of fliers by age for the year 1918 shows the following percentages:

Age.	Per cent of total.	Age.	Per cent of total.
19 years	0.5	29 years	4.5
20 years	4.9	30 years	3.6
21 years	8.9	31 years	2.2
22 years	12.7	32 years	1.2
23 years	13.7	33 years	.6
24 years	12.9	34 years	.5
25 years	11.8	35 years	.2
26 years	10.0	36 years	.3
27 years	6.8		
28 years	5.8	Total	100.0

A comparison of the ages of fliers as shown on special crash reports received during the years 1918 and 1919 and that of fliers on duty for the year 1918, by age groups, shows the following:

	Per cent of total fliers for year 1918.	Per cent of total special crash reports received.
18 to 20 years	5.4	4.64
21 to 23 years	34.4	34.96
24 to 26 years	34.5	30.08
27 to 30 years	20.7	17.60
31 to 35 years	4.7	4.86
36 to 40 years	.3	.96
41 to 45 years		.40
Unknown		6.48
Total	100.0	100.00

ALBERT E. TRUBY,
Colonel, Medical Corps.

STATISTICAL REPORT ON AIRPLANE CRASHES IN THE AIR SERVICE DURING 1920.[1]

(Prepared in the Office of the Chief Surgeon, Air Service.)

A total of 312 crashes of heavier-than-air craft were reported by flight surgeons at Air Service stations during 1920. Those include all crashes of military airplanes in which damage was done to the airplane and is thought to include practically all crashes during the year, and certainly includes all serious crashes.

TABLE 1.—*Crashes by stations.*

(The crash is charged to the station at which the pilot was flying.)

	Crashes.		Crashes.
Aberdeen	4	March	14
Bolling	15	Marfa	7
Camp Bierne	1	Mather	6
Camp Benning	2	Middletown	2
Carlstrom	26	Mitchel	36
Chanute	1	Montgomery	1
Clark	9	Park	1
Coblenz	2	Post	14
El Paso	9	Rich	2
Fairfield	2	Rockwell	7
France	5	Ross	1
Kelly	39	Sanderson	10
Kindley	3	Souther	3
Langley	18	Border Service Activities	7
Laredo	12	Ream	1
Love	2	Red Bluff	2
Luke	9	Fresno	5
McAllen	17		
McCook	17	Total	312

TABLE 2.—*Number of crashes in each month.*

	Crashes.		Crashes.
January	16	August	26
February	24	September	23
March	33	October	15
April	43	November	24
May	34	December	25
June	24		
July	25	Total	312

TABLE 3.—*Crashes according to rank of pilot.*

	Crashes.		Crashes.
Not given	1	Field officer (major and lieutenant colonel)	14
Enlisted	17	Foreign and naval officers	7
Cadet	46		
Second lieutenant	159	Total	312
First lieutenant	44		
Captain	24		

NOTE.—The number of officers in the Air Service in each grade on June 30 and December 31 were as follows:

June 30.		*December 31.*	
Colonels	11	Major generals	1
Lieutenant colonels	14	Brigadier generals	1
Majors	31	Colonels	1
Captains	259	Lieutenant colonels	15
First lieutenants	249	Majors	130
Second lieutenants	507	Captains	86
		First lieutenants	284
		Second lieutenants	497
Total	1,071	Total	1,015

The average number of cadets under training was 220.

TABLE 4.—*Crashes according to rating of pilot.*

	Crashes.		Crashes.
Not given	50	R. M. A	34
No rating	14	M. A	4
Airplane pilot and J. M. A	207		
Airplane observer	1		
Balloon pilot	2	Total	312

NOTE.—The number of officers in the Air Service with flying ratings during 1920 was as follows:

June 30.		*December 31.*	
Air pilots	615	Air pilots	575
M. A	39	M. A	5
J. M. A	66		
Total	720	Total	580

TABLE 5.—*Age of pilot.*

	Crashes.		Crashes.
Not given	6	31 to 35	52
Under 20	6	36 to 40	5
21 to 27	183	41 to 45	4
28 to 30	56	Total	312

TABLE 6.—*Crashes according to class of training which pilot had received.*

	Crashes.		Crashes.
Not given	84	Reconnoissance	43
Cadet training	9	Bombing	43
Pursuit	133	Total	312

TABLE 7.—*Hours dual instruction of pilot prior to crash.*

	Crashes.		Crashes.
Not given	29	26 to 30	13
Less than 6	54	31 to 35	4
6 to 10	123	36 to 40	5
11 to 15	40	41 to 45	13
16 to 20	26		
21 to 25	5	Total	312

TABLE 8.—*Hours solo flying by pilot prior to crash.*

	Crashes.		Crashes.
Not given	19	51 to 70	9
1 to 5	4	70 to 100	10
6 to 10	2	100 to 200	36
11 to 20	10	Over 200	199
21 to 30	10		
31 to 50	13	Total	312

TABLE 9.—*Hours flown by pilot during month preceding crash.*

	Crashes.		Crashes.
Not given	39	26 to 30	24
5 or less	50	31 to 40	16
6 to 10	63	41 to 50	17
11 to 15	41	Over 50	7
16 to 20	37		
21 to 25	18	Total	312

[1] A total of 344 airplane crashes were contained in reports received by the Information Division, Office of the Chief of Air Service, during the calendar year 1921. The discrepancy is accounted for by the fact that 14 crashes were not investigated by flight surgeons because of their minor character and of their occurrence at points somewhat inaccessible to a flight surgeon.

TABLE 10.—*Month in which pilot was last physically examined prior to crash.*

	Crashes.		Crashes.
Not given or more than 12 months previous	59	July	73
January	86	August	14
February	23	September	12
March	13	October	1
April	3	November	1
May	6	December	1
June	20	Total	312

TABLE 11.—*Number of previous crashes of pilot.*

	Crashes.		Crashes.
139 pilots	0	5 pilots	5
77 pilots	1	5 pilots	6
37 pilots	2	2 pilots	7
31 pilots	3	1 pilot	10
15 pilots	4	Total	312

NOTE.—The number of pilots in the Air Service on June 30, 1920, was 720, and on December 31, 1920, was 580.

TABLE 12.—*Physical defects of pilots who crashed as determined by last prior physical examination.*

	Crashes.		Crashes.
No physical defects	284	Ear drum retracted	1
One eye 20/20 to 20/30	3	Unstable nervous system	2
Both eyes 20/20 to 20/30	1	Elbow deformity	1
One or both eyes less than 20/40	1	Color blindness	1
Defective depth perception	1	Nystagmus	1
Esophoria	1	Otitis media	1
Exophoria	1	Nasal obstruction	2
Hyperphoria	5	Hypertrophied tonsils	2
Hyperphoria and esophoria	1	Defective teeth	1
Low prism divergence with esophoria	1	Perforated ear drum	1
		Total	312

The majority of physical defects noted in this table were not causative factors of the crashes reported.

TABLE 14.—*Previous flights made by pilot on date of crash.*

	Crashes.		Crashes.
None	185	Five	8
One	77	Six	2
Two	20	Seven	1
Three	11	Nine	2
Four	6	Total	312

TABLE 15.—*Duration of flight before crash.*

	Crashes.		Crashes.
Not given	18	3 to 4 hours	6
Less than 15 minutes	87	4 to 5 hours	3
15 to 30 minutes	54	5 to 6 hours	1
30 to 60 minutes	65	Over 6 hours	1
1 to 2 hours	58	Total	312
1 to 3 hours	19		

TABLE 16.—*Nature of work being performed at time of crash.*

	Crashes.		Crashes.
Not given	22	Testing	23
Instructing	8	Border patrol	46
Receiving instruction	15	Cross country flights	104
Practice flight	89	Total	312
Stunting or acrobatics	16		
Ferrying	9		

TABLE 17.—*Nature of pilot's duties at field.*

	Crashes.		Crashes.
Not given	23	Regular flying duty including officers on border patrol	63
Under flying training	51	Total	312
Flying instructor	17		
Administrative (adjutant squadron officer, flight surgeon, engineer, radio, supply, etc.)	158		

TABLE 18.—*Result of crash for pilot.*

	Crashes.		Crashes.
Uninjured	217	Killed	34
Slightly injured	48	Total	312
Severely injured	13		

TABLE 19.—*Cockpit of pilot.*

	Crashes.		Crashes.
Not given	23	Single seater	27
Front	217	Total	312
Rear	45		

TABLE 20.—*Result of crash for passenger.*

	Crashes.		Crashes.
No passenger	84	Severely injured	10
Uninjured	160	Killed	12
Slightly injured	46	Total	312

TABLE 21.—*Type of plane.*

	Crashes.		Crashes.
Not given	3	SE-5A	5
JN-4H	26	La Pere	2
JN-4HG	1	Nieuport	3
JN-6H	26	Sopwith	1
JN-6HG1	9	Fokker	4
JN-6H0	1	Vought	2
Curtiss unclassified	16	Thomas Morse	2
DH-4	68	Avro	1
DH-4B	124	All others	4
De Haviland unclassified	1	Total	312
SE-5	13		

TABLE 23.—*Damage to plane.*

	Crashes.		Crashes.
Not given or not known	6	Propeller and wings broken	26
Undercarriage broken	16	Fuselage broken	26
Propeller broken	10	Complete wreck or washout	134
Wings broken	15	Plane burned	16
Undercarriage and propeller broken	37	Total	312
Undercarriage and wings broken	26		

TABLE 24.—*Day of week.*

	Crashes.		Crashes.
Monday	51	Saturday	40
Tuesday	50	Sunday	23
Wednesday	54	Total	312
Thursday	47		
Friday	47		

TABLE 25.—*Time of day.*

	Crashes.		Crashes.
Not given	1	2 to 4 p. m.	65
1 to 6 a. m.	6	4 to 6 p. m.	43
6 to 8 a. m.	7	6 to 8 p. m.	8
8 to 10 a. m.	49	Total	312
10 to 12 m.	100		
12 to 2 p. m.	33		

TABLE 26.—*Weather.*

	Crashes.		Crashes.
Clear	238	Stormy	7
Hazy	11	Rain or snow	5
Windy	21	Foggy	9
Gusty	4	Total	312
Cloudy	17		

TABLE 27.—*Terrain.*

	Crashes.		Crashes.
Not given	29	Soft (ploughed or muddy)	48
Level	138	Rough	2
Woody	15	Water	10
Hilly	23	Total	312
Rolling	38		
Marshy	9		

TABLE 28.—*Stage of flight at which accident occurred.*

	Crashes.		Crashes.
Not given	5	Landing	183
Getting off	43	Total	312
In air	81		

TABLE 29.—*Altitude at which trouble began.*

	Crashes.		Crashes.
On ground	100	3,000 to 6,000 feet	14
Less than 100 feet	69	6,000 to 10,000 feet	1
100 to 300 feet	39	10,000 to 15,000 feet	2
300 to 600 feet	21	Over 15,000 feet	1
600 to 1,000 feet	12	Total	312
1,000 to 3,000 feet	43		

TABLE 30.—*Distance of site of crash from field.*

	Crashes.		Crashes.
On home field	106	6 to 8 miles	4
One-half mile or less	23	8 to 10 miles	5
One-half to 1 mile	5	10 to 15 miles	20
1 to 2 miles	15	Over 15 miles	121
2 to 4 miles	9	Total	312
4 to 6 miles	4		

TABLE 31.—*Cause of crash as reported by flight surgeon.*

	Crashes.		Crashes.
Not known	5	Terrain conditions	45
Failure of engine	94	Weather conditions	27
Defect of plane	26	Unavoidable	6
Fire	4	Controls refusing to work	3
Flat turn	5	Inexperience	7
Collision	20	Air pocket	1
Nose dive	1	Gasoline exhausted	8
Side slipping	3	Spin	6
Stall	16	Poor pilotage	7
Misjudged landing	19	Total	312
Pancaking	9		

TABLE 32.—*Cause of crash as determined by crash board.*

	Crashes.		Crashes.
Not known	70	Terrain conditions	17
Failure of engine	45	Weather conditions	6
Defect in plane	11	Unavoidable	4
Fire	3	Inexperience	6
Flat turn	4	Air pocket	1
Collision	10	Gasoline exhausted	5
Nose dive	1	Spin	3
Side slipping	3	Poor pilotage	6
Stall	8	No crash board	104
Misjudged landing	3	Total	312
Pancaking	2		

TABLE 33.—*Arrival of first aid.*

	Crashes.		Crashes.
Not given or not needed	98	1 hour	8
Immediately	70	2 hours	4
5 minutes	98	3 hours	1
10 minutes	19	4 hours or over	1
20 minutes	7	Total	312
30 minutes	6		

TABLE 34.—*Ambulance.*

	Crashes.		Crashes.
None	193	Airplane ambulance	10
Horse drawn	3	Total	312
Motor	106		

Number of flying hours from January 1, 1920, to December 31, 1920: 74,105.

NOTE.—As an example of the information which can be secured, the following correlated data on crashes and injuries in crashes of DH-4's and DH-4B's is given.

Comparison of results between crashes of DH-4 and DH-4B airplanes.

TOTAL NUMBER OF DH-4 CRASHES, 68.

	Total.	No passenger or not given.	Uninjured	
			Number.	Rate.
Result to pilot	68	....	55	80.86
Result to passenger	68	9	41	69.48

	Slightly injured.		Severely injured.		Killed.	
	Number.	Rate.	Number.	Rate.	Number.	Rate.
Result to pilot	4	5.88	3	4.42	6	8.84
Result to passenger	13	22.03	2	3.38	3	5.08

TOTAL NUMBER OF DH-4B CRASHES, 124.

	Total.	No passenger or not given.	Uninjured	
			Number.	Rate.
Result to pilot	124	....	104	83.87
Result to passenger	124	11	90	79.64

	Slightly injured.		Severely injured.		Killed.	
	Number.	Rate.	Number.	Rate.	Number.	Rate.
Result to pilot	10	8.06	3	2.41	7	5.64
Result to passenger	18	15.92	......	....	5	4.42

Of the above airplanes which crashed, 1 DH-4 and 8 DH-4B's were burned.

According to information obtained from the supply group, the total number of flights made by the DH-4 plane was 6,713, total flying time 11,162.21 hours. The total number of flights made by the DH-4B plane being 12,322 and total flying time 24,404.90 hours.

From the above comparison it appears that the DH-4B is much safer for the pilot than the DH-4. The degree of safety as shown by the percentages of killed and seriously injured being as 8.05 in the DH-4B's to 13.26 in the DH-4's. The danger to the passenger is also less in crashes of the DH-4B than in crashes of DH-4, the ratio being as 5.08 in the crashes of DH-4B's to 8.64 in crashes of DH-4's.

In crashes of DH-4's in which pilots were injured or killed, 12 out of 13 pilots were piloting from the front cockpit. In the crashes of the DH-4B's in which the pilots were injured, or killed all were piloting from the front cockpit.

The danger of fire in the DH-4B, however, appears to be much greater than in the DH-4.

STATISTICAL REPORT ON AIRPLANE CRASHES IN THE AIR SERVICE DURING THE PERIOD JANUARY 1, 1921, TO DECEMBER 31, 1921.

(Prepared in the Office of the Chief, Medical Section.)

INDEX TO TABLES.

A total of 328 [1] crashes of heavier-than-air craft were reported by flight surgeons at Air Service stations of the Regular Army during the period covered by this report. These are all of the crashes occurring at stations where there was a flight surgeon. In addition, reports of two crashes, occurring at stations where there were no flight surgeons, and in which there were fatalities, were obtained from the training and operations group. The two fatalities caused by a bomb explosion at Aberdeen are not included in these statistics, as this was not considered an airplane crash. The crashes reported include all accidents in which there was any material damage to the airplane as the result of a crash. There was but one crash by a lighter-than-air craft during the year with no deaths resulting.

[1] A total of 314 airplane crashes were contained in reports received by the Information Division, Office of the Chief of Air Service during the calendar year 1921. The discrepancy is accounted for by the fact that 14 crashes were not investigated by flight surgeons because of their minor character and of their occurrence at points somewhat inaccessible to a flight surgeon.

TABLE 1.—*Crashes by stations.*

(The crash is charged to the station at which the pilot was flying.)

Aberdeen, Md	1	Fort Sheridan	1
Bolling Field	15	Godman Field	1
Border service activities	16	Kelly Field	39
Camp Holabird	1	Kindley Field	2
Camp Lewis	2	Langley Field	65
Carlstrom Field	33	Luke Field	4
Chanute Field	5	McCook Field	11
Clark Field	4	March Field	9
Coblenz, Germany	3	Mather Field	26
Crissy Field	1	Mitchel Field	10
Dorr Field	1	Montgomery, Ala	2
Ellington Field	12	Pope Field	1
Eugene, Oreg	4	Post Field	57
Fort Howard	1	Scott Field	1
Fort McPherson	1		
Fort Omaha	1	Total	330

TABLE 2.—*Number of crashes in each month.*

	Crashes.		Crashes.
January	23	August	44
February	20	September	43
March	25	October	19
April	22	November	15
May	27	December	18
June	33	Total	330
July	41		

TABLE 3.—*Crashes according to rank of pilot.*

	Crashes.		Crashes.
Not given	1	Lieutenant colonel	4
Enlisted	13	Foreign officer	5
Cadet	62	Marine Corps officer	2
Second lieutenant	31	Naval officer	1
First lieutenant	147	Total	330
Captain	43		
Major	21		

The average number of cadets in training during the period covered by this report was 180.

TABLE 4.—*Crashes according to rating of pilot.*

	Crashes.		Crashes.
Not given	35	Airplane pilot and J. M. A.	198
No rating	89	R. M. A	8
		Total	330

On December 31, 1921, there were 861 Air Service officers of the Regular Army with flying ratings. The number of Reserve officers with flying ratings on December 31 was approximately 5,000.

TABLE 5.—*Age of pilot.*

	Crashes.		Crashes.
Not given	7	41 to 45	5
21 to 27	185	46 to 50	1
28 to 30	74	Total	330
31 to 35	48		
36 to 40	10		

97992—22——2

TABLE 6.—*Crashes according to class of training which pilot had received.*

	Crashes.		Crashes.
Not given	26	Bombing	69
Cadet training	18	Two or more of above	20
Pursuit	101	Total	330
Reconnaissance	96		

TABLE 7.—*Hours dual instruction of pilot prior to crash.*

	Crashes.		Crashes.
Not given	22	26 to 30	12
Less than 6	41	31 to 35	6
6 to 10	119	36 to 40	2
11 to 15	51	41 to 45 or above	25
16 to 20	30	Total	330
21 to 25	22		

TABLE 8.—*Hours solo flying by pilot prior to crash.*

	Crashes.		Crashes.
Not given	14	51 to 70	10
1 to 5	5	71 to 100	21
6 to 10	5	100 to 200	73
11 to 20	7	Over 200	161
21 to 30	12	Total	330
31 to 50	22		

TABLE 9.—*Hours flown by pilot during month preceding crash.*

	Crashes.		Crashes.
Not given	14	26 to 30	5
5 or less	63	31 to 40	27
6 to 10	51	41 to 50	6
11 to 15	57	Over 50	10
16 to 20	44	Total	330
21 to 25	33		

TABLE 10.—*Month in which pilot was last physically examined prior to crash.*

	Crashes.		Crashes.
Not given, or more than 12 months previous	17	1921:	
1920:		January	10
January	1	February	6
May	1	March	8
June	8	April	3
July	69	May	2
August	5	June	4
September	13	July	154
October	10	August	7
November	4	September	3
December	5	Total	330

TABLE 11.—*Number of previous crashes by pilots.*

	Previous crashes.		Previous crashes.
154 pilots	0	4 pilots	5
87 pilots	1	1 pilot	6
49 pilots	2	2 pilots	7
23 pilots	3	2 pilots	9
8 pilots	4	330	

TABLE 12.—*Physical defects of pilots who crashed as determined by last prior physical examination.*

	Pilots.		Pilots.
No physical defects	306	Flat foot	1
One eye between 20/20 and 20/30	1	Varicocele	1
Both eyes 20/20 to 20/30	2	Overweight	1
Hyperphoria	4	Cardiac murmurs	1
Exophoria	1	Cardiac arrhythmia	1
Angle of convergence	1	Hypertrophied tonsils	1
Hearing—one ear defective	6	Hypertrophied turbinate	1
Hearing—both ears defective	1	Total	330
Unstable nervous system	1		

The majority of physical defects noted in this table were not causative factors of the crashes reported.

TABLE 14.—*Previous flights made by pilot on date of crash.*

	Flights.		Flights.
215 pilots	0	2 pilots	6
57 pilots	1	2 pilots	7
25 pilots	2	2 pilots	8
14 pilots	3	5 pilots	9
5 pilots	4	330	
3 pilots	5		

TABLE 15.—*Duration of flight before crash.*

	Crashes.		Crashes.
Not given	20	3 to 4 hours	14
Less than 15 minutes	94	4 to 4 hours	2
15 to 30 minutes	67	5 to 6 hours	2
31 to 60 minutes	54	Over 6 hours	2
1 to 2 hours	58	Total	330
2 to 3 hours	17		

TABLE 16.—*Nature of work being performed at time of crash.*

	Crashes.		Crashes.
Not given	1	Border or forest patrol	18
Instructing	10	Cross country flight	129
Receiving instruction	13	Bombing or bombing practice	11
Practice flight	103	Total	330
Stunting or acrobatics	7		
Ferrying	17		
Testing	21		

TABLE 17.—*Nature of pilot's duties at field.*

	Crashes.		Crashes.
Not given	11	Administrative (adjutant, squadron officer, flight surgeon, engineer, radio, supply, etc.)	137
Under flying training	122	Total	330
Flying instructor	8		
Regular flying duty, including border and forest patrol	52		

TABLE 18.—*Result of crash for pilot.*

	Crashes.		Crashes.
Uninjured	238	Killed	38
Slightly injured	40	Total	330
Severely injured	14		

Rank of pilots killed.

	Crashes.		Crashes.
Enlisted	4	Captain	5
Cadet	6	Major	1
Second lieutenant	6	Total[1]	38
First lieutenant	16		

TABLE 19.—*Cockpit of pilot.*

	Crashes.		Crashes.
Not given	11	Single seater	44
Front	243	Total	330
Rear	32		

TABLE 20.—*Result of crash for passengers.*

	Passengers.		Passengers.
No passenger	100	Severely injured	13
Uninjured	185	Killed	31
Slightly injured	26	Total	355

There were 6 passengers, including 2 civilians, killed in one crash, and also 1 passenger severely injured and 1 (civilian) killed in one crash. One other civilian passenger was killed, making a total of 4 civilians killed who were flying as passengers in Army aeroplanes. Three passengers were killed and 1 severely injured in a single crash, and in another crash 2 passengers were killed.

[1] Statistics of the Information Division, Office of the Chief of Air Service give the number of pilots killed as 39, number of passengers, 32; total, 71. The discrepancy is occasioned by the inclusion by the Information Division of 2 fatalities (one pilot and one passenger) which occurred at Aberdeen when the tail skid of an airplane struck and exploded a bomb.

Rank of passengers killed.

Civilian	4	Lieutenant colonel	1
Enlisted	14	Total	31
Cadet	5		
First lieutenant	7		

TABLE 21.—*Type of plane.*

	Crashes.		Crashes.
JN-4H	6	Fokker	1
JN-4HG	1	SE-5	28
JN-6H	33	SE-5A	9
JN-6HG1	1	Nieuport	1
Curtiss unclassified	14	Martin bomber	10
Caproni	1	Thomas Morse	5
DH-4	6	All other	12
DH-4B	195	Total	330
De Haviland unclassified	6		
Handley-Page	1		

TABLE 23.—*Damage to plane.*

	Crashes.		Crashes.
Not given or not known	4	Propeller and wings broken	10
Undercarriage broken	13	Fuselage broken	42
Propeller broken	11	Complete wreck or washout	154
Wings broken	6	Burned	26
Undercarriage and propeller broken	39	Total	330
Undercarriage and wings broken	25		

TABLE 24.—*Day of week.*

	Crashes.		Crashes.
Monday	60	Saturday	36
Tuesday	40	Sunday	25
Wednesday	62	Total	330
Thursday	55		
Friday	52		

TABLE 25.—*Time of day.*

	Crashes.		Crashes.
Not given	3	2 to 4 p. m	66
1 to 6 a. m	1	4 to 6 p. m	38
6 to 8 a. m	8	6 to 8 p. m	19
8 to 10 a. m	58	8 to 12 p. m	9
10 to 12 m	87	Total	330
12 to 2 p. m	41		

TABLE 26.—*Weather.*

	Crashes.		Crashes.
Not given	2	Rain or snow	7
Clear	221	Foggy	11
Hazy	6	Dark or at night	4
Windy	35	Total	330
Cloudy	22		
Stormy	22		

TABLE 27.—*Terrain.*

	Crashes.		Crashes.
Not given	11	Soft (ploughed or muddy land)	31
Level	151	Thickly settled or small	9
Woody	12	Rough	49
Hilly	20	Water	22
Rolling	20	Total	330
Marshy	5		

TABLE 28.—*Stage of flight at which accident occurred.*

	Crashes.		Crashes.
Not given	2	On ground	1
Getting off	63	Total	330
In air	89		
Landing	175		

TABLE 29.—*Altitude at which trouble began.*

	Crashes.		Crashes.
On ground	130	3,000 to 6,000 feet	16
Less than 100 feet	60	6,000 to 10,000 feet	6
100 to 300 feet	44	10,000 to 15,000 feet	1
300 to 600 feet	18	Total	330
600 to 1,000 feet	11		
1,000 to 3,000 feet	41		

TABLE 30.—*Distance of site of crash from field.*

	Crashes.		Crashes.
On home field	102	6 to 8 miles	8
One-half mile or less	18	8 to 10 miles	4
One-half to 1 mile	9	10 to 15 miles	13
1 to 2 miles	14	Over 15 miles	143
2 to 4 miles	8	Total	330
4 to 6 miles	11		

TABLE 31.—*Cause of crash as reported by flight surgeon.*

	Crashes.		Crashes.
Not known	8	Spin	6
Acute physical impairment	1	Poor pilotage	19
Failure of engine	84	At night	6
Defect in plane	31	Out of oil	2
Flat turn	1	Tire trouble	5
Collision	17	Stoppage in gas feed	8
Side slipping	5	Bursted oil lead	1
Skidding	2	Fatigue of pilot	1
Stall	9	Unavoidable	7
Misjudged landing	31	Controls jammed	4
Pancaking	10	Air pocket	1
Terrain conditions	32	Commercial gasoline	1
Weather conditions	24	Total	330
Inexperience	4		
Gasoline exhausted	10		

TABLE 32.—*Cause of crash as determined by crash board.*

	Crashes.		Crashes.
Not known	27	Inexperience	1
Failure of engine	27	Gasoline exhausted	3
Defect in plane	9	Spin	4
Collision	12	Poor pilotage	6
Side slipping	3	At night	5
Skidding	2	Out of oil	1
Controls jammed	2	Tire trouble	3
Air pocket	1	Stoppage in gas feed	3
Stall	7	Unavoidable	7
Misjudged landing	10	No crash board	161
Pancaking	7	Total	330
Terrain conditions	17		
Weather conditions	12		

TABLE 33.—*Arrival of first aid.*

	Crashes.		Crashes.
Not given or not needed	97	31 minutes to 1 hour	5
Immediately	121	1 to 2 hours	5
3 to 5 minutes	57	2 to 3 hours	1
6 to 10 minutes	14	3 to 4 hours or over	9
11 to 20 minutes	11	Total	330
21 to 30 minutes	10		

TABLE 34.—*Type of ambulance used.*

	Crashes.		Crashes.
None	190	All others	14
Motor ambulance	109	Total	330
Airplane ambulance	17		

Number of flying hours from January 1, 1921, to November 30, 1921: 65,882.53. The number of flying hours for December, 1921, is not at present available.

NOTE.—The above statistics have not been analyzed or correlated, but all crash reports have been coded and code cards prepared and punched, so that analysis and correlation of any of the statistics given above can be made at any time and in a few minutes.

ALBERT E. TRUBY,
Colonel, Medical Corps, U. S. A.,
Chief of Medical Section.

STATISTICS SHOWING RESULTS OF PHYSICAL EXAMINATIONS FOR FLYING, 1920.

Number of examinations arranged according to the purpose for which the examination was given.

Civilian applicants for appointment as cadets, Air Service	232
Enlisted applicants for appointment as cadets, Air Service	640
Officers for commission in the Air Service, Regular Army	1,138
Semiannual examinations (given in January and July of each year)	1,237
Special examinations (given when ordered by the commanding officer or thought advisable by the flight surgeon)	17
For transfer to the Air Service from other branches of the Army	44
For training of nonflying officers detailed with the Air Service and nonflying Air Service Officers, including Medical, Naval, and Foreign Officers	192
Total physical examinations for flying during 1920	3,500

(*a*) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS OF CIVILIAN APPLICANTS FOR APPOINTMENT AS CADETS AIR SERVICE.

Age.	Total examined.	Qualified.		Disqualified.		Waived for all service.		Waived, lighter than air.		Waived for observer.	
		Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Not given	9	5	55.55	4	44.45						
Under 21 years	53	25	47.17	28	52.83						
21-27 years	163	105	64.41	58	35.59						
28-30 years	5	1	20.00	3	60.00	1	20.00				
31-35 years	2	1	50.00	1	50.00						
36-40 years											
41-45 years											
46-50 years											
Total	232	137	59.05	94	40.52	1	.43				

(*b*) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS OF ENLISTED APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

Not given	22	14	63.64	8	36.36						
Under 21 years	205	146	71.22	57	27.80	2	0.98				
21-27 years	339	249	73.45	85	25.07	4	1.18	1	0.30		
28-30 years	34	17	50.00	15	44.11	2	5.89				
31-35 years	25	10	40.00	15	60.00						
36-40 years	12	2	16.66	10	83.34						
41-45 years	3			3	100.00						
46-50 years											
Total	640	438	68.43	193	30.15	8	1.26	1	.16		

(*c*) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS FOR FLYING OF FORMER TEMPORARY OFFICERS FOR COMMISSION IN THE AIR SERVICE, REGULAR ARMY.

Not given	5	2	40.00	1	20.00	2	40.00				
Under 21 years											
21-27 years	648	556	85.80	56	8.62	34	5.27	2	0.31		
28-30 years	226	181	80.08	31	13.73	14	6.19				
31-35 years	168	146	86.87	14	8.37	8	4.76				
36-40 years	58	44	75.86	14	24.14						
41-45 years	22	17	77.27	2	9.09	1	4.55	1	4.55	1	4.54
46-50 years	11	5	45.45	5	45.45			1	9.10		
Total	1,138	951	83.57	123	10.81	59	5.18	4	.35	1	.09

(*d*) RESULTS, BY AGES, OF SEMIANNUAL PHYSICAL EXAMINATIONS OF FLIERS.

(A physical examination for flying is required twice a year of all pilots. Some of those disqualified in this table were for temporary disabilities As soon as such disabilities have been corrected by proper treatment a reexamination is given, and the pilot is again authorized to fly. See next table.)

Not given	38	30	78.95	6	15.79	2	5.26				
Under 21 years	74	66	89.19	5	6.76	3	4.05				
21-27 years	611	536	87.56	38	6.22	38	6.22				
28-30 years	204	178	87.26	12	5.88	14	6.86				
31-35 years	198	158	79.79	22	11.12	17	8.59			1	0.58
36-40 years	77	61	79.22	7	9.09	6	7.79	2	2.60	1	1.30
41-45 years	22	12	54.55	3	13.63	4	18.18	2	9.09	1	4.55
46-50 years	12	4	33.33	5	41.67	3	25.00				
Total	1,237	1,045	84.47	98	7.93	87	7.04	4	.32	3	.24

(e) RESULTS, BY AGES, OF SPECIAL PHYSICAL EXAMINATIONS OF FLIERS.

(Upon advice of flight surgeons.)

Age.	Total examined.	Qualified.		Disqualified.		Waived for all service.		Waived, lighter than air.		Waived for observer.	
		Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Not given											
Under 21 years	1	1	100.00								
21-27 years	12	7	58.34	4	33.33	1	8.33				
28-30 years	2	1	50.00			1	50.00				
31-35 years	1	1	100.00								
36-40 years											
41-45 years											
46-50 years	1	1	100.00								
Total	17	11	64.71	4	23.53	2	11.76				

(f) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS OF APPLICANTS (OFFICERS) FOR TRANSFER TO THE AIR SERVICE FROM OTHER BRANCHES OF THE SERVICE.

Not given	2			2	100.00						
Under 21 years											
21-27 years	18	8	44.44	10	55.56						
28-30 years	10	7	70.00	3	30.00						
31-35 years	6	4	66.67	2	33.33						
36-40 years	4	2	50.00	2	50.00						
41-45 years	3	1	33.33	1	33.33			1	33.33		
46-50 years	1			1	100.00						
Total	44	22	50.00	21	47.73			1	2.27		

(g) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS FOR FLYING TRAINING OF NONFLYING OFFICERS DETAILED WITH THE AIR SERVICE AND NONFLYING AIR SERVICE OFFICERS (INCLUDING MEDICAL, NAVAL, AND FOREIGN OFFICERS).

(The percentage of officers who were qualified as shown by this table is large owing to the fact that many nonflying officers of the Air Service, and those of other branches attached thereto, had previously been disqualified for flying, or knew that they had physical defects, and therefore did not take the examination.)

Not given	8	8	100.00								
Under 21 years											
21-27 years	93	88	94.63	5	5.37						
28-30 years	37	35	94.58	1	2.71	1	2.71				
31-35 years	34	32	94.12	2	5.88						
36-40 years	10	8	80.00	1	10.00	1	10.00				
41-45 years	9	7	77.78	2	22.22						
46-50 years	1	1	100.00								
Total	192	179	93.23	11	5.73	2	1.04				

SUMMARY.

Results of physical examinations irrespective of classes.

Qualified for flying or flying training	2,783
Disqualified for flying or flying training	544
Waived for both heavier and lighter than air	159
Waived for lighter than air only	10
Waived for observer only	4
Total physical examinations for flying during 1920	3,500

Results, by ages, of physical examinations—Summary of Tables (a), (b), (c), (d), (e), (f), and (g) above.

Age.	Total examined.	Qualified.		Disqualified.		Wiaved for all service.		Waived, lighter than air.		Waived for observer.	
		Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Not given	84	59	70.24	21	25.00	4	4.76				
Under 21 years	333	238	71.47	90	27.03	5	1.50				
21-27 years	1,885	1,549	82.17	256	13.59	77	4.09	3	0.15		
28-30 years	518	420	81.09	65	12.54	33	6.37				
31-35 years	434	352	81.11	56	12.88	25	5.77			1	0.24
36-40 years	161	117	72.67	34	21.12	7	4.34	2	1.25	1	.62
41-45 years	59	37	62.71	11	18.64	5	8.48	4	6.78	2	3.39
46-50 years	26	11	42.31	11	42.31	3	11.54	1	3.84		
Total	3,500	2,783	79.51	544	15.56	159	4.54	10	.28	4	.11

Causes of disqualification for which no waivers were granted.

(All disqualifying defects found are given, in some cases there being several defects found in the same man, so that the total number of defects found does not correspond with the number disqualified.)

1. CIVILIAN APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given	1	1	1		2																5
Under 21 years	8		4	3		1	1				2			1			4	1		21	46
21 to 27 years	18	3	10	5	2	4	3	2			3	1	1		2		4			35	93
28 to 30 years	2																			4	6
31 to 35 years																				1	1
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total	29	4	15	8	4	5	4	2			5	1	1	1	2		8	1		61	151

2. ENLISTED APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given	2		4					1									1			4	12
Under 21 years	16	2	8	3	1	3	2	3	1								3			39	81
21 to 27 years	24	5	16	7	3	8	1	1	1		1				1		4			43	115
28 to 30 years	3	1	1	1	2															8	16
31 to 35 years	2		3	1													1			12	19
36 to 40 years	1			1	1	1	1													10	15
41 to 45 years	1																			2	3
Total	49	8	32	13	7	12	4	5	2		1				1		9			118	261

3. FORMER TEMPORARY OFFICERS FOR COMMISSION IN THE AIR SERVICE, REGULAR ARMY.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given			1																		1
Under 21 years																					
21 to 27 years	12	2	8	4		4	2		1		2		2		1	1	3	1		32	75
28 to 30 years	8	2	5	4		1						1	1	1		1	1	1	1	18	45
31 to 35 years	4	1	4	1		3			1		1				2		1			8	26
36 to 40 years	4		6	2	1						2				1			1		8	25
41 to 45 years																				2	2
46 to 50 years	2			1																2	5
Total	30	5	24	12	1	8	2		2		5	1	3	1	4	2	5	3	1	70	179

4. SEMIANNUAL PHYSICAL EXAMINATIONS OF FLIERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given	3	1	1			1														3	9
Under 21 years	1	1	1	1		1		1												3	9
21 to 27 years	8	4	13		1	4					1				1		1		2	23	58
28 to 30 years	3		1	2							2						2	1		8	19
31 to 35 years	5		2	2	1	6		1									1			16	34
36 to 40 years	4		2			1												1		7	15
41 to 45 years	1										1									3	5
46 to 50 years	1		1			1														5	8
Total	26	6	21	5	2	14		2			4				1		4	2	2	68	157

5. SPECIAL PHYSICAL EXAMINATIONS OF FLIERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years			1																	5	6
28 to 30 years																					
31 to 35 years																					
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total			1																	5	6

6. APPLICANTS FOR TRANSFER TO THE AIR SERVICE FROM OTHER BRANCHES OF THE ARMY.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given	1	1																			2
21 to 27 years	3				1		1	2					1		1					6	15
28 to 30 years	2	1			1	1														1	6
31 to 35 years						2															2
36 to 40 years						2															2
41 to 45 years			1																		1
46 to 50 years	1																			1	2
Total	7	2	1		2	5	1	2					1		1					8	30

Causes of disqualification for which no waivers were granted—Continued.

7. PHYSICAL EXAMINATIONS FOR FLYING TRAINING OF NONFLYING OFFICERS DETAILED WITH THE AIR SERVICE AND NONFLYING AIR SERVICE OFFICERS, ETC.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years	4	2	1	1	1															1	10
28 to 30 years	1				1																2
31 to 35 years																				2	2
36 to 40 years								1													1
41 to 45 years	2			1	1																4
46 to 50 years																					
Total	7	2	1	2	3			1												3	19

SUMMARY OF TABLES 1 TO 7 ABOVE SHOWING NO WAIVERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Civilian applicants	29	4	15	8	4	5	4	2			5	1	1	1	2		8	1		61	151
Enlisted applicants	49	8	32	13	7	12	4	5	2		1				1		9			118	261
For commission	30	5	24	12	1	8	2		2		5	1	3	1	4	2	5	3	1	70	179
Semiannual examination	26	6	21	5	2	14		2			4				1		4	2	2	68	157
Special examinations			1																	5	6
For transfer	7	2	1		2	5	1	2					1		1					8	30
For detail	7	2	1	2	3			1												3	19
Total	148	27	95	40	19	44	11	12	4		15	2	5	2	9	2	26	6	3	333	803

Causes of disqualification waived for both heavier and lighter than air.

(No serious defects were waived.)

1. CIVILIAN APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years																					
28 to 30 years																				1	1
31 to 35 years																					
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total																				1	1

2. ENLISTED APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Under 21 years	2																				2
21 to 27 years	1		2			1															4
28 to 30 years																				2	2
Total	3		2			1														2	8

3. FORMER TEMPORARY OFFICERS FOR COMMISSION IN THE AIR SERVICE, REGULAR ARMY.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given	1					1														1	3
Under 21 years																					
21 to 27 years	9	3	6	2		8					5								2	5	40
28 to 30 years	4	1	5	2		3					2						1			1	19
31 to 35 years	3		1	1		5															10
36 to 40 years																					
41 to 45 years				1																	1
46 to 50 years																					
Total	17	4	12	6		17					7						1		2	7	73

Causes of disqualification waived for both heavier and lighter than air—Continued.

4. SEMIANNUAL PHYSICAL EXAMINATIONS OF FLIERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given	2																				2
Under 21 years			2			1															3
21 to 27 years	7	1	18	3	1	8														9	47
28 to 30 years	2		6	3		3														4	18
31 to 35 years	5		5	2		6														2	20
36 to 40 years			4			2														2	8
41 to 45 years	3					3															6
46 to 50 years						3															3
Total	19	1	35	8	1	26														17	107

5. SPECIAL PHYSICAL EXAMINATIONS OF FLIERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years				1																	1
28 to 30 years			1																		1
31 to 35 years																					
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total			1	1																	2

7. OFFICERS DETAILED WITH THE AIR SERVICE AND NONFLYING AIR SERVICE OFFICERS, ETC.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
28 to 30 years	1					1														1	3
36 to 40 years	1					1														1	3
Total	2					2														2	6

Causes of disqualification waived for lighter than air only.

2. ENLISTED APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years	1																				1
28 to 30 years																					
31 to 35 years																					
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total	1																				1

3. FORMER TEMPORARY OFFICERS FOR COMMISSION IN THE AIR SERVICE, REGULAR ARMY.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
21 to 27 years	1	1					1														3
41 to 45 years	1																				1
46 to 50 years	1	1	1																		3
Total	3	2	1				1														7

4. SEMIANNUAL PHYSICAL EXAMINATIONS OF FLIERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years																					
28 to 30 years																					
31 to 35 years																					
36 to 40 years	2																				2
41 to 45 years	2				1																3
46 to 50 years																					
Total	4				1																5

Causes of disqualification waived for lighter than air only—Continued.

6. APPLICANTS FOR TRANSFER TO THE AIR SERVICE FROM OTHER BRANCHES OF THE ARMY.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
41 to 45 years			1	1																	2
Total			1	1																	2

Causes of disqualification waived for observer only.

3. FORMER TEMPORARY OFFICERS FOR COMMISSION IN THE AIR SERVICE, REGULAR ARMY.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years																					
28 to 30 years																					
31 to 35 years																					
36 to 40 years																					
41 to 45 years						1															1
46 to 50 years																					
Total						1															1

4. SEMIANNUAL PHYSICAL EXAMINATIONS OF FLIERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
31 to 35 years						1															1
36 to 40 years	1																			1	2
41 to 45 years						1															1
Total	1					2														1	4

Summary of Tables 1, 2, 3, 4, 5, and 7 (heavier and lighter than air), Tables 2, 3, 4, and 6 (lighter than air only), and Tables 3 and 4, above (observer only), showing waivers of physical defects.

SUMMARY OF TABLES 1 TO 7 ABOVE SHOWING WAIVERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Civilian applicants																				1	1
Enlisted applicants	4		2			1														2	9
For commission	20	6	13	6		18	1				7						1		2	7	81
Semiannual examinations	24	1	35	8	2	28														18	116
Special examinations			1	1																	2
For transfer to Air Service			1	1																	2
For detail with Air Service	2					2														2	6
Total	50	7	52	16	2	49	1				7						1		2	30	217

STATISTICS SHOWING RESULTS OF PHYSICAL EXAMINATIONS FOR FLYING, 1921.

Number of examinations arranged according to the purpose for which the examination was given.

Civilian applicants for appointment as cadets, Air Service	145
Enlisted applicants for appointment as cadets, Air Service	377
Officers for commission in the Air Service, Regular Army	167
For rating on completion of flying training	199
Semiannual examinations (given in January and July of each year)	1,521
Special examinations (given when ordered by the commanding officer or thought advisable by the flight surgeon)	49
For transfer to the Air Service from other branches of the Army	123
For training of nonflying officers detailed with the Air Service and nonflying Air Service officers, including medical, naval, and foreign officers, and Reserve Officers Training Corps students	245
For commission in the Air Service Reserve Corps under flying status	11
Total physical examinations for flying during 1921	2,837

(a) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS OF *CIVILIAN* APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

Age.	Total examined.	Qualified.		Disqualified.		Waived for all service.		Waived, lighter than air.		Waived for observer.	
		Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Not given											
Under 21 years	41	24	58.54	16	39.02	1	2.44				
21-27 years	104	60	57.69	44	42.31						
28-30 years											
31-35 years											
36-40 years											
41-45 years											
46-50 years											
Total	145	84	57.93	60	41.38	1	.69				

(b) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS OF *ENLISTED* APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

Not given											
Under 21 years	103	63	61.16	39	37.87	1	0.97				
21-27 years	260	162	62.31	98	37.69						
28-30 years	8	2	25.00	5	62.50	1	12.50				
31-35 years	3			2	66.67	1	33.33				
36-40 years	1			1	100.00						
41-45 years											
46-50 years	2			2	100.00						
Total	377	227	60.21	147	38.99	3	.80				

(c) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS FOR FLYING OF FORMER TEMPORARY OFFICERS FOR COMMISSION IN THE AIR SERVICE, REGULAR ARMY.

Not given	1	1	100.00								
Under 21 years	1	1	100.00								
21-27 years	138	108	78.26	29	21.02	1	0.72				
28-30 years	24	19	79.17	5	20.83						
31-35 years	3	2	66.67	1	33.33						
36-40 years											
41-45 years											
46-50 years											
Total	167	131	78.44	35	20.96	1	.60				

(d) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS FOR RATING ON COMPLETION OF FLYING TRAINING.

Age.	Total examined.	Qualified.		Disqualified.		Waived for all servicei		Waived, lighter than air.		Waived for observer.	
		Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Age not given											
Under 21 years	23	21	91.30	1	4.35	1	4.35				
21-27 years	127	119	93.70	2	1.57	6	4.73				
28-30 years	17	15	88.24			1	5.88	1	5.88		
31-35 years	17	17	100.00								
36-40 years	8	7	87.50			1	12.50				
41-45 years	3	3	100.00								
46-50 years	4	2	50.00			2	50.00				
Total	199	184	92.46	3	1.51	11	5.53	1	.50		

(e) RESULTS, BY AGES, OF SEMI-ANNUAL PHYSICAL EXAMINATIONS OF FLIERS.

(This table includes Regular Army officers, cadets and Reserve officers. A physical examination is required of fliers twice a year by existing regulations, but in 1921 the January examination was omitted and only the July semiannual examination held. Some of those disqualified in this table were for temporary disabilities. As soon as such disabilities are corrected by proper treatment a reexamination is given, and, if the disqualification is found on such reexamination to have been removed, the pilot is authorized to fly.)

Age not given	1			1	100.00						
Under 21 years	47	44	93.62	1	2.13	2	4.25				
21-27 years	788	719	91.24	32	4.06	37	4.70				
28-30 years	332	294	88.55	14	4.22	23	6.93	1	0.30		
31-35 years	239	198	82.84	12	5.02	28	11.72			1	0.42
36-40 years	76	57	75.00	10	13.16	9	11.84				
41-45 years	30	21	70.00	2	6.67	6	20.00	1	3.33		
46-50 years	7	2	28.57	1	14.29	3	42.86	1	14.28		
51-55 years	1	1	100.00								
Total	1,521	1,336	87.84	73	4.80	108	7.10	3	.20	1	.06

(e) (1) RESULTS, BY AGES, OF SEMIANNUAL PHYSICAL EXAMINATIONS SHOWING NUMBER OF RESERVE OFFICERS.

Age not given				1							
Under 21 years											
21-27 years		129		16		4					
28-30 years		36		6							
31-35 years		18		2							
36-40 years		6		1							
41-45 years											
46-50 years											
Total		189		26		4					

(e) (2) RESULTS, BY AGES, OF SEMIANNUAL PHYSICAL EXAMINATIONS SHOWING NUMBER OF CADETS.

Age not given											
Under 21 years		35				2					
21-27 years		181		5		5					
28-30 years		11									
31-35 years		4									
36-40 years		2									
41-45 years											
46-50 years											
Total		233		5		7					

(f) RESULTS, BY AGES, OF SPECIAL PHYSICAL EXAMINATIONS OF FLIERS.

(Upon advice of flight surgeon.)

Age not given											
Under 21 years											
21-27 years	26	21	80.77	5	19.23						
28-30 years	14	12	85.71	2	14.29						
31-35 years	6	2	33.33	2	33.33	2	33.33				
36-40 years	2	2	100.00								
41-45 years	1					1	100.00				
46-50 years											
Total	49	37	75.51	9	18.37	3	6.12				

(*g*) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS OF APPLICANTS (OFFICERS) FOR TRANSFER TO THE AIR SERVICE FROM OTHER BRANCHES OF THE SERVICE.

Age.	Total examined.	Qualified.		Disqualified.		Waived for all service.		Waived, lighter than air.		Waived for observer.	
		Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Age not given											
Under 21 years	2	2	100.00								
21-27 years	69	58	84.06	11	15.94						
28-30 years	29	24	82.76	5	17.24						
31-35 years	19	13	68.42	6	31.58						
36-40 years	2	1	50.00	1	50.00						
41-45 years	1	1	100.00								
46-50 years	1			1	100.00						
Total	123	99	80.49	24	19.51						

(*h*) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS FOR FLYING TRAINING OF NONFLYING OFFICERS DETAILED WITH THE AIR SERVICE AND NONFLYING AIR SERVICE OFFICERS (INCLUDING MEDICAL, NAVAL AND FOREIGN OFFICERS, AND STUDENTS, RESERVE OFFICERS' TRAINING CORPS).

Age not given											
Under 21 years	110	65	59.09	45	40.91						
21-27 years	93	59	63.44	34	36.56						
28-30 years	9	6	66.67	2	22.22	1	11.11				
31-35 years	18	11	61.11	6	33.33	1	5.56				
36-40 years	9	7	77.78	2	22.22						
41-45 years	3	2	66.67			1	33.33				
46-50 years	3	1	33.33	1	33.33	1	33.33				
Total	245	151	61.64	90	36.73	4	1.63				

(*i*) RESULTS, BY AGES, OF PHYSICAL EXAMINATIONS FOR COMMISSION IN THE AIR SERVICE RESERVE CORPS, UNDER FLYING STATUS.

Age not given											
Under 21 years											
21-27 years	7	6	85.71	1	14.29						
28-30 years	1	1	100.00								
31-35 years	3	3	100.00								
36-40 years											
41-45 years											
46-50 years											
Total	11	10	90.91	1	9.09						

SUMMARY.

Results of physical examinations irrespective of classes.

Qualified for flying, or flying training	2,259
Disqualified for flying, or flying training	442
Waived for both heavier and lighter than air	131
Waived for lighter than air only	4
Waived for observer only	1
Total physical examinations for flying during 1921	2,837

Results, by ages, of physical examinations—Summary of Tables (a), (b), (c), (d), (e), (f), (g), (h), and (i), above.

Age.	Total examined.	Qualified.		Disqualified.		Waived for all service.		Waived, lighter than air.		Waived for observer.	
		Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Not given	2	1	50.00	1	50.00						
Under 21 years	327	220	67.28	102	31.19	5	1.53				
21-27 years	1,612	1,312	81.39	256	15.88	44	2.73				
28-30 years	434	373	85.95	33	7.60	26	5.99	2	0.46		
31-35 years	308	246	79.87	29	9.42	32	10.39			1	0.32
36-40 years	98	74	75.51	14	14.29	10	10.20				
41-45 years	38	27	71.05	2	5.27	8	21.05	1	2.63		
46-50 years	17	5	29.41	5	29.41	6	35.30	1	5.88		
51-55 years	1	1	100.00								
Total	2,837	2,259	79.61	442	15.59	131	4.62	4	.14	1	.04

Causes of disqualification for which no waivers were granted.

(All disqualifying defects found are given, in some cases there being several defects found in the same man, so that the total number of defects found does not correspond with the number disqualified.)

CLASS 1.—CIVILIAN APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years	4	3	6	2	1	3	1	1	1						1					10	33
21 to 27 years	12	1	18	4	5	4	2	2	2						1					28	79
28 to 30 years																					
31 to 35 years																					
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total	16	4	24	6	6	7	3	3	3						2					38	112

CLASS 2.—ENLISTED APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Under 21 years	10	2	11	7	4	3	4	9	3		1				2					28	84
21 to 27 years	25	7	36	11	12	5	9	14									2	1		63	185
28 to 30 years		1	1			1	1	1	1											4	10
31 to 35 years						1														2	3
36 to 40 years																				1	1
46 to 50 years	1		1																	1	3
Total	36	10	49	18	16	10	14	24	4		1				2		2	1		99	286

CLASS 3.—FORMER TEMPORARY OFFICERS FOR COMMISSION IN THE AIR SERVICE, REGULAR ARMY.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years	1	2	7	2	3	5		1			3								1	20	45
28 to 30 years	2		1												1					2	6
31 to 35 years	1		1																	2	4
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total	4	2	9	2	3	5		1			3				1				1	24	55

CLASS 4.—FOR RATING ON COMPLETION OF FLYING TRAINING.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Under 21 years																				1	1
21 to 27 years			2																	3	5
Total			2																	4	6

CLASS 5.—SEMIANNUAL PHYSICAL EXAMINATIONS OF FLIERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																				1	1
Under 21 years			1	1																	2
21 to 27 years	10	2	8	2	1	2	3	2	1											23	54
28 to 30 years	3		4			1			1						1					12	22
31 to 35 years	4		2	1		2														10	19
36 to 40 years	3	1	4			3														7	18
41 to 45 years	1		2	1																1	5
46 to 50 years						1															1
Total	21	3	21	5	1	9	3	2	2						1					54	122

CLASS 6.—SPECIAL PHYSICAL EXAMINATIONS OF FLIERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
21 to 27 years	2		2	1	1			1												2	9
28 to 30 years			1																	1	2
31 to 35 years			1			1														2	4
Total	2		4	1	1	1		1												5	15

Causes of disqualification for which no waivers were granted—Continued.

CLASS 7.—APPLICANTS FOR TRANSFER TO THE AIR SERVICE FROM OTHER BRANCHES OF THE ARMY.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years	4	2	2	2		3	1													13	27
28 to 30 years	1		1		1	1					1									6	11
31 to 35 years	1		1		2	4														2	10
36 to 40 years		1	1																	1	3
41 to 45 years																					
46 to 50 years																				1	1
Total	6	3	5	2	3	8	1				1									23	52

CLASS 8.—PHYSICAL EXAMINATIONS FOR FLYING TRAINING OF NONFLYING OFFICERS DETAILED WITH AIR SERVICE AND NONFLYING AIR SERVICE OFFICERS, RESERVE OFFICERS' TRAINING CORPS, STUDENTS, ETC.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Under 21 years	6		6	13	1	4	1	1			3									24	59
21 to 27 years	4		9	7	2	2		1	1		2										28
28 to 30 years	1		1		1																3
31 to 35 years	3	2	2		2		2													3	14
36 to 40 years	2		2	1																	5
46 to 50 years		1			1	1					1										4
Total	16	3	20	21	7	7	3	2	1		6									27	113

CLASS 9.—FOR COMMISSION IN THE AIR SERVICE RESERVE CORPS UNDER FLYING STATUS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years			1																		1
28 to 30 years																					
31 to 35 years																					
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total			1																		1

SUMMARY OF TABLES 1 TO 9 ABOVE SHOWING NO WAIVERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Civilian applicants	16	4	24	6	6	7	3	3	3						2					38	112
Enlisted applicants	36	10	49	18	16	10	14	24	4		1				2		2	1		99	286
For commission	4	2	9	2	3	5		1			3				1				1	24	55
For rating			2																	4	6
Semiannual examinations	21	3	21	5	1	9	3	2	2						1					54	122
Special examinations	2		4	1	1	1		1												5	15
For transfer	6	3	5	2	3	8	1				1									23	52
For detail	16	3	20	21	7	7	3	2	1		6									27	113
For commission in Air Service Reserve			1																		1
Total	101	25	135	55	37	47	24	33	10		11				6		2	1	1	274	762

Causes of disqualification waived for both heavier and lighter than air.

(No serious defects were waived.)

CLASS 1.—CIVILIAN APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years											1										1
21 to 27 years																					
28 to 30 years																					
31 to 35 years																					
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total											1										1

CLASS 2.—ENLISTED APPLICANTS FOR APPOINTMENT AS CADETS, AIR SERVICE.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Under 21 years			1																		1
28 to 30 years																				1	1
Total			1																	1	2

CLASS 3.—FORMER TEMPORARY OFFICERS FOR COMMISSION IN THE AIR SERVICE, REGULAR ARMY.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years				1																	1
28 to 30 years																					
31 to 35 years																					
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total				1																	1

CLASS 4.—FOR RATING ON COMPLETION OF FLYING TRAINING.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Under 21 years						1															1
21 to 27 years	5	1				1														1	8
28 to 30 years	1																				1
36 to 40 years						1															1
46 to 50 years	1			1		2															4
Total	7	1		1		5														1	15

CLASS 5.—SEMIANNUAL PHYSICAL EXAMINATIONS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years	2			1																	3
21 to 27 years	11	1	8	6		7	1												1	8	43
28 to 30 years	9	1	8	2		6														1	27
31 to 35 years	8		9	6		10	1													3	37
36 to 40 years	3			1		3														2	9
41 to 45 years	1		1			4															6
46 to 50 years	1					3															4
Total	35	2	26	16		33	2												1	14	129

CLASS 6.—SPECIAL PHYSICAL EXAMINATIONS OF FLIERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
31 to 35 years	1		2	1																	4
36 to 40 years																					
41 to 45 years	1																				1
46 to 50 years																					
Total	2		2	1																	5

CLASS 8.—TRAINING OF OFFICERS DETAILED WITH AIR SERVICE, NONFLYING AIR SERVICE OFFICERS, RESERVE OFFICERS' TRAINING CORPS, STUDENTS, ETC.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years																					
28 to 30 years	1																				1
31 to 35 years						1															1
36 to 40 years																					
41 to 45 years						1															1
46 to 50 years	1					1															2
Total	2					3															5

No defects were waived for both heavier and lighter than air in classes 7 and 9.

Causes of disqualification waived for lighter than air only.

(No serious defects were waived.)

CLASS 4.—FOR RATING ON COMPLETION OF FLYING TRAINING.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years																					
28 to 30 years	1	1																			2
31 to 35 years																					
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total	1	1																			2

CLASS 5.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
28 to 30 years	1	1																			2
41 to 45 years	1		1			1															3
46 to 50 years	1		1																		2
Total	3	1	2			1															7

NOTE.—No defects waived for lighter than air in classes 1, 2, 3, 6, 7, 8, and 9.

Causes of disqualification waived for observer only.

(No serious defects were waived.)

CLASS 5.—SEMIANNUAL PHYSICAL EXAMINATIONS OF FLIERS.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Age not given																					
Under 21 years																					
21 to 27 years																					
28 to 30 years																					
31 to 35 years						1															1
36 to 40 years																					
41 to 45 years																					
46 to 50 years																					
Total						1															1

No defects were waived for observer only in classes 1, 2, 3, 4, 6, 7, 8, and 9.

Summary of classes 1, 2, 3, 4, 5, 6, and 8 (heavier and lighter than air), classes 4 and 5 (lighter than air only), and class 5 (observer only) above, showing waivers of physical defects.

	Vision.	Depth perception.	Muscle balance.	Accommodation.	Refraction.	Hearing.	Nystagmus.	Past pointing.	Falling.	Height.	Weight.	Aortic insufficiency.	Aortic stenosis.	Aortic and mitral lesions.	Mitral insufficiency.	Mitral stenosis.	Neuro-Circu-Asth.	Ankylosis, bony.	Ankylosis, fibrous.	All others.	Total.
Civilian applicants											1										1
Enlisted applicants			1																	1	2
Commission in air service				1																	1
Rating after training	8	2		1		5														1	17
Semiannual examinations	38	3	28	16		35	2												1	14	137
Special examinations	2		2	1																	5
Detailed with air service	2					3															5
Total	50	5	31	19		43	2				1								1	16	168

NOTE.—Thirty-four physical examinations have been received since the above report was closed.

ALBERT E. TRUBY,
Colonel, Medical Corps, U. S. A.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV May 15, 1922 No. 341

DESCRIPTION OF McCOOK FIELD 5-FOOT WIND TUNNEL

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by
E. N. Fales, Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 10, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

Certificate: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

DESCRIPTION OF McCOOK FIELD 5-FOOT WIND TUNNEL.

The new wind tunnel of the Air Service Engineering Division has for object to afford the service more convenient aerodynamic testing facilities than have hitherto been available. The past few years have seen an increase in the amount of this testing, until in 1920 outside contracts amounted to $30,000. In consideration of this annual outlay, and of the inconvenience resulting from such an arrangement, it has been found desirable to erect a new wind tunnel at McCook Field, and construction commenced in June, 1921.

It is not necessary here to discuss the use to which wind tunnels are put further than to state that by their means the designer acquires much of his aerodynamic data. The method involves small-scale models of any desired design, which are subjected to an artificial air blast, and the resulting air forces measured by a balance. The coefficients of "Lift," "Drag," etc., are thus determined, and may be applied to aircraft when suitably corrected for scale effect.

This correction may reach a value such that special requirements are introduced into the design of the wind tunnel. Within certain limits we are led by the law of dynamic similarity to prefer a wind tunnel which will afford the maximum product speed × size. Thus, theoretically, a tunnel large enough to test a full-sized airplane at normal air speed may be replaced by a one-fourth scale tunnel operating at quadruple speed. Practically, we have not yet attained a tunnel greater than one-sixth scale, the more popular size being one-twelfth scale; and if we increase the velocity to correspond we reach air flow régimes where the forces created can not always be interpreted by means of the law of dynamic similarity. Evaluation of the "scale effect" at high velocities is not yet satisfactorily understood, nor will it be until our fund of knowledge of high-speed phenomena is increased. It is thus obvious from aerodynamic considerations that our choice of a wind-tunnel design must be something of a compromise. Furthermore, for the more practical consideration of size and cost of plant, we must again compromise.

If our wind tunnel is to afford the maximum sphere of usefulness, it must therefore be more than a copy of some other existing tunnel, and it must be designed to accommodate the necessary aerodynamic characteristics, together with the conditions imposed by power and expense limits.

COST OF PLANT.

It is not difficult to secure in a moderate-sized wind tunnel the full flight velocity; but velocities sufficient to offset the scale effect are impracticable. The power will vary approximately as the cube of the velocity and the square of the dimension, and from this standpoint large size and slow speed are easier to attain than small size and high speed. But the larger the volume of air handled, the larger must be the building; for the air exhausted from the tunnel, recirculating through the building toward the intake, must there have small entrance velocity; and this requires that the building have large height and width The cost of such a building varies with the cube of diameter and with the first power of the velocity; hence from consideration of space available, the small high velocity wind tunnel is preferable.

DETERMINING OF CHARACTERISTICS OF THE McCOOK FIELD 5-FOOT WIND TUNNEL.

For the Army Air Service a desirable combination is an 8-foot diameter tunnel having a velocity equivalent to that of a full-sized airplane, say, 150 miles per hour. For practical reasons (at the date of the order of the present wind tunnel project, no building was available on McCook Field large enough for an 8-foot tunnel) a smaller diameter, 5 feet, was chosen as the maximum in which reasonable smoothness of air flow at conventional speeds could be expected. In such a tunnel fairly high velocity may be obtained for special work, such, for example, as problems in propeller design. Due to uncertainty of future location, portability is an advantage favoring the smaller size. In the entire design provision is made such that the plant can be moved in the future and increased in size when moved to its permanent location.

POWER PLANT.

The design of the wind tunnel has been arranged to utilize electric motors already available, and no outside purchase has been necessary beyond the motor-generator equipment. Each of the two fans is driven by two Sprague dynamometers, which were reserved from the Liberty engine production equipment. The result is that economy of first cost is combined with efficiency of operation.

POWER ECONOMY.

Where large power is involved as in the case of a high speed wind tunnel it is important to apply to the design all available considerations of power economy. The most important item has to do with the air flow in the tunnel downstream of the model; that is, in the cone and through the fan. It is of interest to mention here the considerations determining the design of such a cone.

DECELERATING CONE.

The decelerating cone, which is so important in a high-speed wind tunnel, is familiar to the ventilating engineer and hydraulic engineer in commercial application; it is found in ventilating circuits under the term of "blower chimney" and in hydraulic power plants under the name of "draft tube." It is also used in the Venturi tube flow meter for measuring flow of water in pipes. According to the Bernouilli theorem, such a cone facilitates interchange of the pressure and velocity energies of the fluid passing through it; for the fluid, changing its velocity in proportion as it traverses the varying areas of cross section of such a

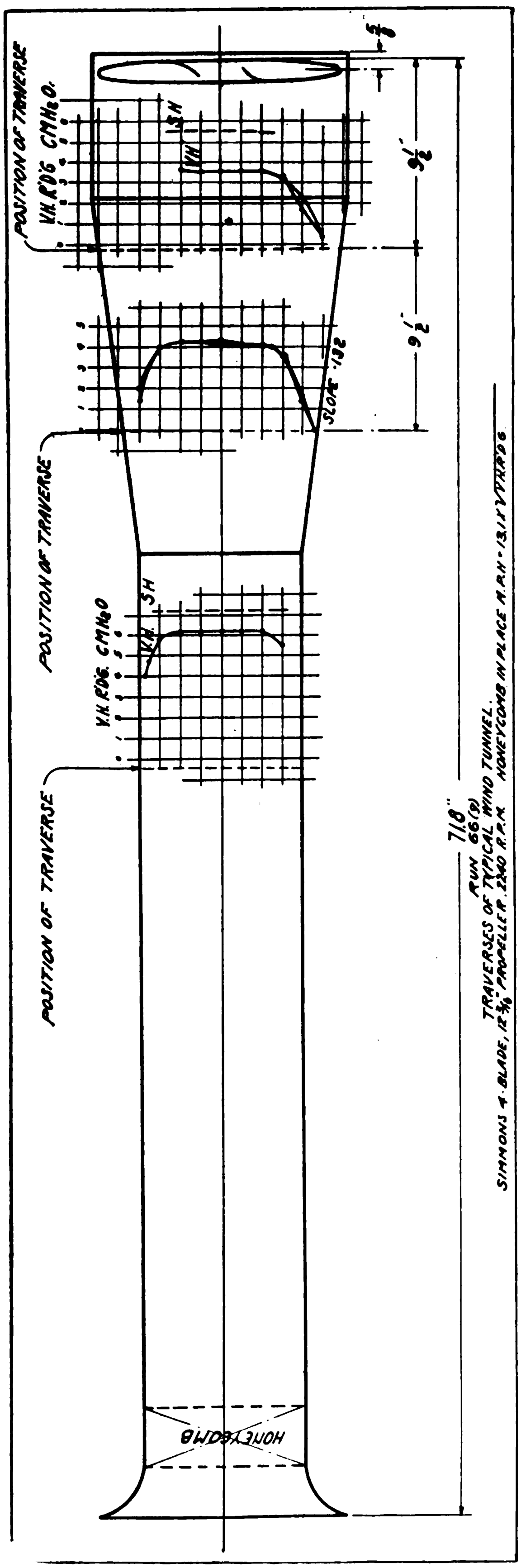


FIG. 1—Air flow, in wide angle cone, traverses of typical wind tunnel.

cone, also undergoes a change of pressure at each successive point. In a properly designed decelerating cone the total energy of air moving toward the large end may be within 10 per cent of its value at the small end.

No thorough analysis of the aerodynamic characteristics of this interchange of energy has been perfected, but we may obtain a very good idea of the nature of the flow distribution by means of experiments, such as have been developed in the Air Service, made either on model or full-scale wind tunnels. Figure 1 shows the velocity distribution in a 15° cone fixed to an 8-inch model wind tunnel; the boundary of the undisturbed air flow does not extend to the cone walls, but is separated from them by an annular space of reduced pressure. In figure 1 the cone angle is too great. Figure 2 shows the distribution of dynamic pressure in the McCook Field 14-inch wind tunnel. The space is occupied by flowing air whose velocity and energy is less than the corresponding value within the central core, the equivalent loss of pressure being greater at points successively nearer to the walls of the cone. Figure 3 shows the longitudinal pressure gradient in the 14-inch tunnel.

Evidence has been found that air, when decelerating, will maintain an expansion angle somewhat smaller than the angle which has been proved best for these cones. Particular evidence of the formation of the "virtual" cone was found in the model wind tunnel tests made in connection with the design of the McCook Field high-speed wind tunnel, and may also be observed by reference to tests shown in figure 2. For a rough visualization of the nature of the air flow within the decelerating cone, we arrive at the best conception if we imagine the flow shape to be that of a "virtual" cone, the walls surrounding it being simply a barrier to prevent inflow of outside atmospheric air.

Figure 4 is a chart showing the degree of energy interchange to be expected from cones of varying length. We observe that but small profit in energy recovery follows from increasing the large diameter to a value greater than two and one-half times the small diameter.

GENERAL DESCRIPTION OF McCOOK FIELD 5-FOOT WIND TUNNEL.

The foregoing analysis of cone functioning has been emphasized because of its major importance and is fundamental in the successful design of a high-speed plant. The other parts of the wind tunnel are similarly subject to analysis; the cylindrical portion, the intake bell, the blades or vanes for straightening the air flow, the honeycomb, and the "return flow equalizers," etc., are other technical items which are of importance in producing smooth air flow in the wind tunnel. These will not be discussed here.

GENERAL SHAPE.

Figure 5 shows the wind tunnel in cross section, located in a standard steel hangar. From the dimensions and constructions there shown, the reader will observe that several processes have been evolved tending toward economy of construction and operation. The center line of the wind tunnel is elevated above the floor an amount such that the return flow area above and below bear the proper relation to each other. Several of the roof trusses are raised in order to accommodate the wind tunnel struc-

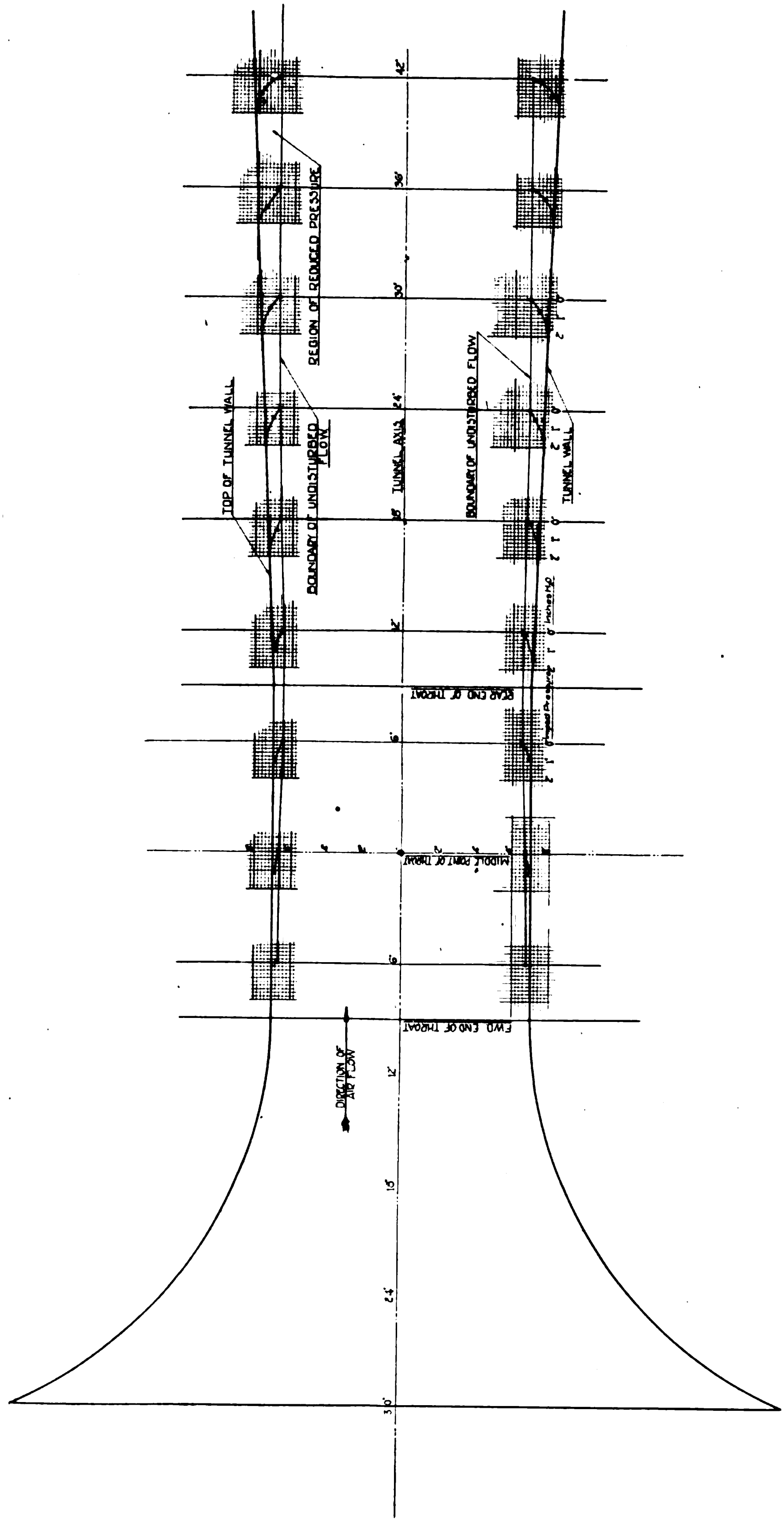


FIG. 2.—Longitudinal and lateral traverse of dynamic heads in McCook Field 14-inch wind tunnel.

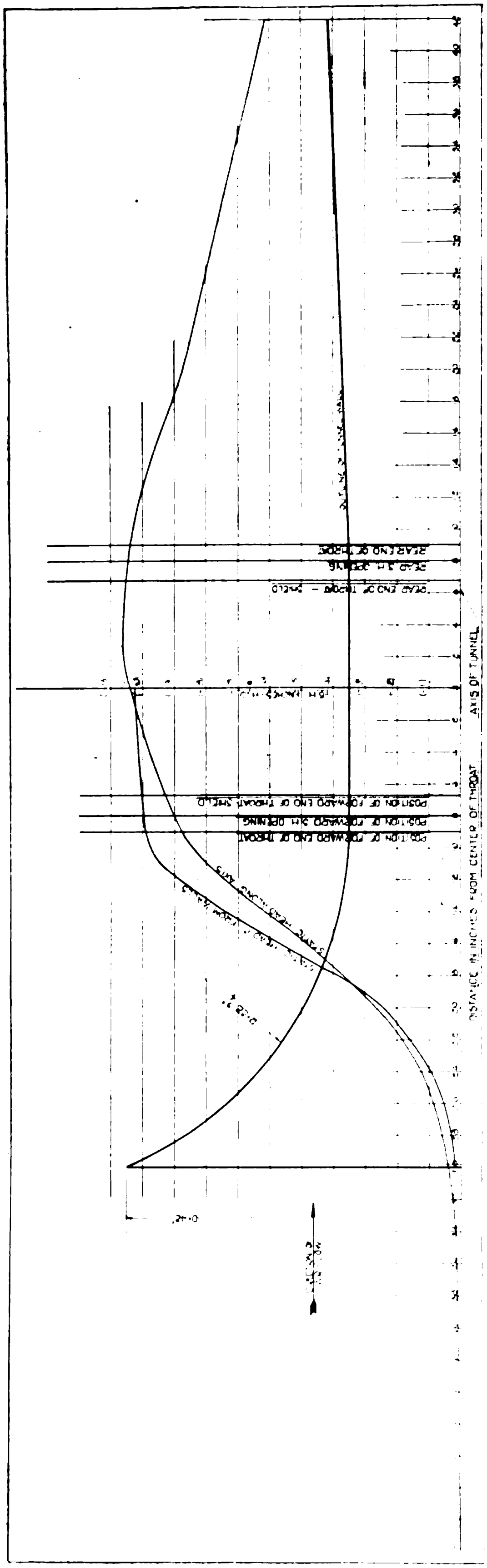


Fig. 3.—Longitudinal traverse of static heads.

ture; the horizontal stringer is removed and replaced by a post and knee brace. The proportions of the hangar, with low roof and wide span, offer poor accommodation for proper return flow uniformity of the air. Furthermore, this type of hangar is not impervious to entrance of atmospheric pressure changes due to wind gusts, and special precautions are therefore requisite.

FOUNDATIONS.

Foundations for the fan motors are set in the north end of the hangar. The balance foundation is located approximately 40 feet from the south end. No foundations have been thought necessary for the tubular wooden structure, whose weight is adequately taken up by the heavy concrete floor installed in the hangar.

EXPERIMENTAL PORTION.

The cylindrical portion of the tunnel consists of a 12-foot and a 6-foot section, either or both of which may be used. The flanged joints are drilled to templates in such a way that various sections are interchangeable. A carefully aligned rail carries this cylindrical portion, which can be rolled in or out as desired and set in proper alignment. Provision has been made for removing such members of the supporting framework as conflict during its movement with the balance foundation.

METHOD OF CONSTRUCTING THE TUBE AND CONE.

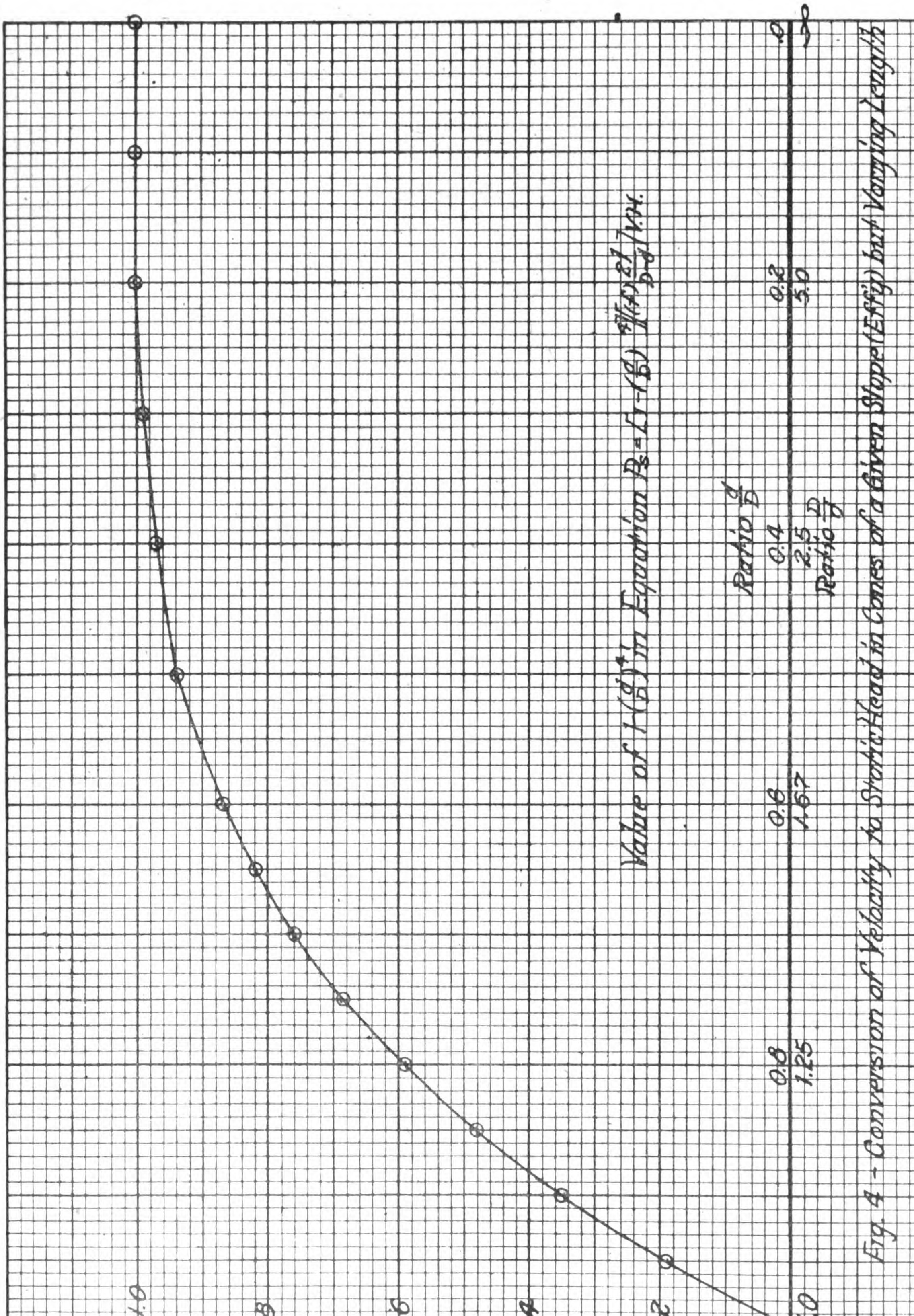
The method of construction adopted is thought to be an improvement over previous methods, embodying the advantage of a tubular column. Narrow staves of seasoned Port Arthur cedar were cut in a four-side molder with the tongue-and-groove joint principle. These were placed together inside circumferential rings, and glued and screwed to each other, each section of the tunnel thus being a rigid unit. For the cylindrical portion, the rings were glued up out of segments to a thickness of about 4 inches and a depth of about 6 inches. To make the individual curved segments large square boards were first glued up and the curved segments cut out in such a fashion that the inner curvature of one was in juxtaposition with the outer curvature of the next, thus effecting economy of material. In gluing up the rings screws were used rather than clamps.

TURNING THE RINGS.

The smaller rings were turned on an overhung lathe. The flat sides were turned and the curved surfaces were cut in a special shaper, using a turned template. The larger rings for the cone were similarly shaped in an Oliver woodworking machine, rotating on a vertical axis under a rotary cutter having adjustable head, the latter being swung to cut the proper angle, whether for the cylindrical portion, which was 90°, or the conical portion which was $86\frac{1}{2}°$ and $82\frac{1}{2}°$. (See Fig. 6.)

SUPPORTING FRAMEWORK.

The tubular portion, having been completed as a self-sustained unit, is supported by means of cradles under each alternate ring. Each cradle consists of a curved sheet-steel ledge supported by battered legs reaching



Value of $1-(\frac{d}{D})^4$ in Equation $B_s = [1-(\frac{d}{D})^4](1+f)\frac{2l}{D-d}$ V.H.
Ratio $\frac{d}{D}$
Ratio $\frac{D}{d}$
1.0
.8
.6
.4
.2
0
0.8
1.25
0.6
1.67
0.4
2.5
0.2
5.0
1.0
∞
Fig. 4 - Conversion of Velocity to Static Head in Cones of a Given Slope (Eff'y) but Varying Length

FIG. 4.

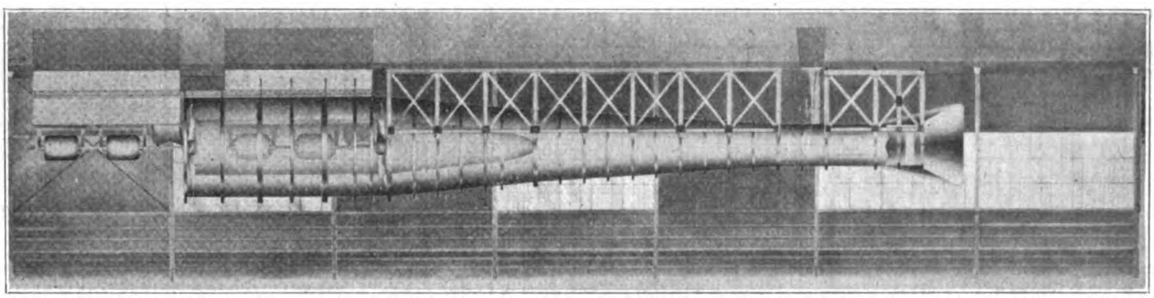


FIG. 5.—Outline diagram of 5-foot wind tunnel.

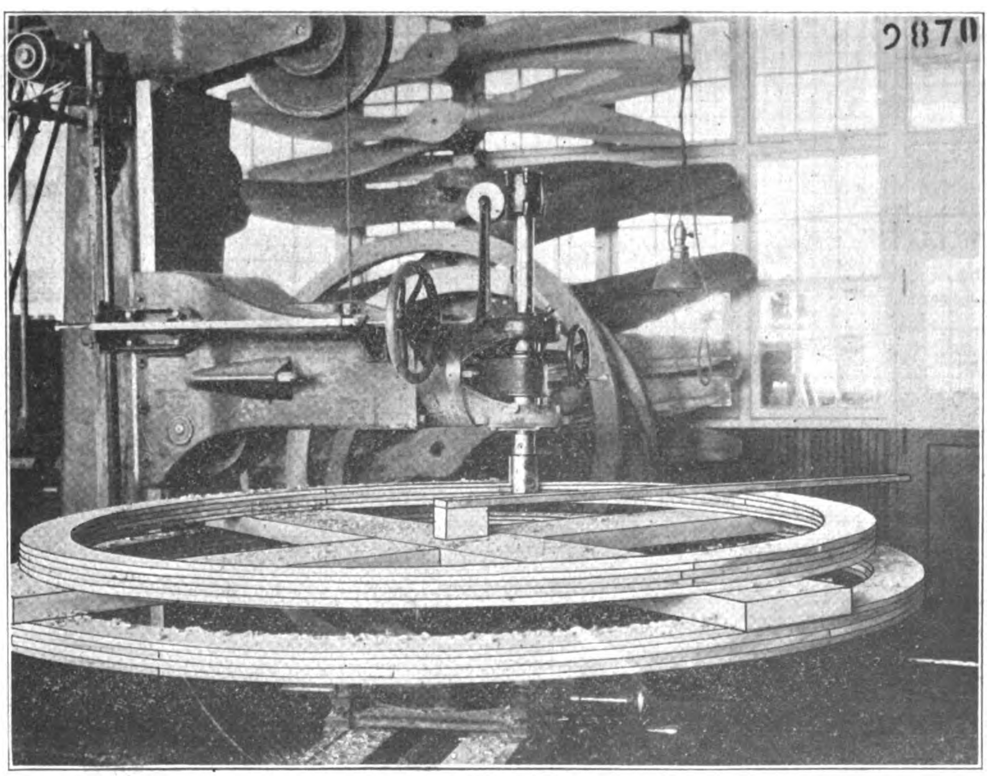


FIG. 6 - Turning large wind tunnel rings on Oliver woodworking machine.

to the floor and properly trussed. The top of the framework receives steel straps which pass above and below the ring for the purpose of anchoring the same to the framework.

PORTABLE FEATURES.

In order to accommodate tests of maximum range and to make use of either of the two balances provided, the cylindrical portions, with their supporting framework, are mounted on wheels, and when not anchored they can roll along small rails set on the concrete floor. Thus any desired combination of experimental chambers may be brought into action.

BALANCES.

Two balances are provided for the wind tunnel. For low speed the NPL type balance is used in order to preserve continuity with earlier testing for the Air Service wherein this type of balance was used. For high speeds a balance of the Wright type will be utilized on the principle shown in figure 8. The NPL balance being of a conventional type need not be described, but the Wright balance introduces new features. It is fastened to the tunnel itself, which is made of cast iron at this point. There is a linkage mechanism above and below the cast-iron tube, and each end of a vertically placed model is thus supported in separate linkages; these linkages move in unison. The advantages of the Wright type balance are that it eliminates velocity fluctuations, which are, of course, the worst factor with which we have to deal in wind-tunnel operation. Incidental virtues are that it enables the operator to read directly the ratio lift over drag; also that it enables the operator to reverse the model conveniently for check tests. The Wright type balance has not previously been used for high-power work, its special scope having been for precision tests in Mr. Wright's laboratory. Its application to the large high-speed wind tunnel is a development which has required considerable change from the original design.

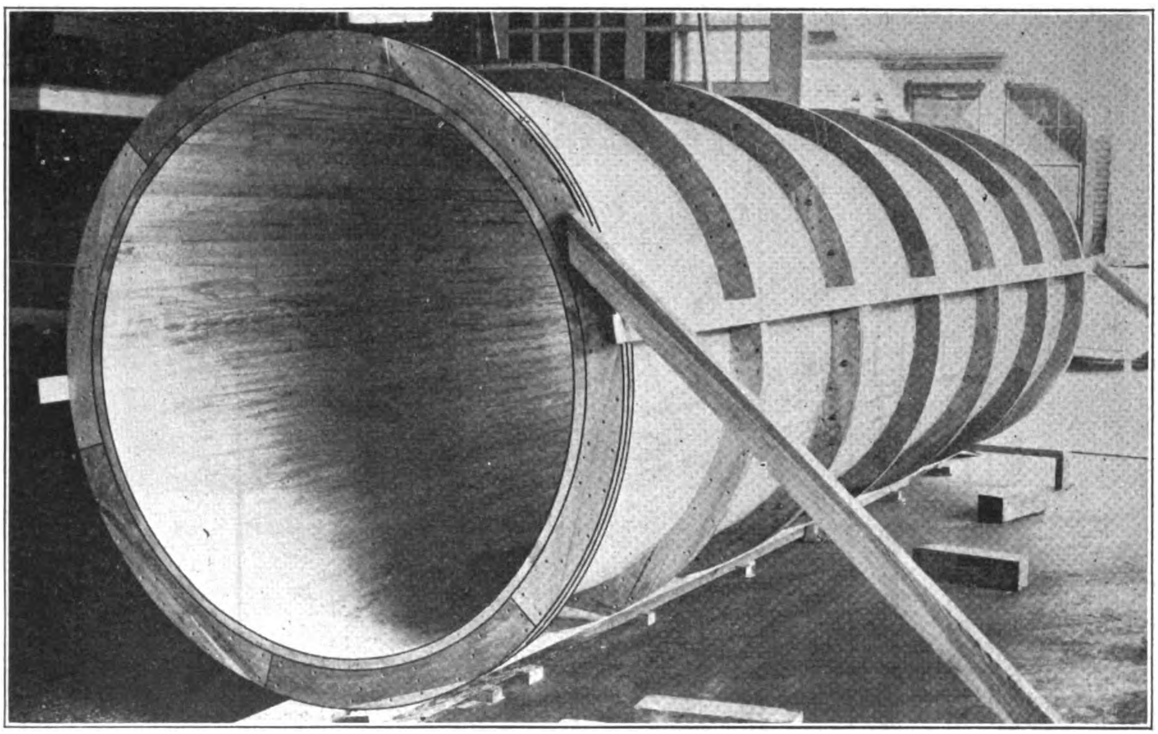


FIG. 7.—Built-up section of cylindrical portion of 5-foot wind tunnel.

PROPELLERS.

The propeller system, while new as applied to wind tunnels, is one which is dictated by considerations of the entire problem. It is known that the character of the air flow depends somewhat upon the uniformity of pressure traverse at the fan end of the cone. It is also known that if the traverse is not uniform, power losses may occur. For both reasons it becomes essential that a wind-tunnel fan have a unit thrust which is as nearly as possible identical at all portions of the propeller disk. We are at once led by these considerations to the conclusion that the linear velocity of the fan blade elements must not be of wide range, and, therefore, that we must blank off a considerable hub diameter.

In the McCook Field design the fans have a diameter of 11 feet 11 inches, with a hub diameter of 8 feet 8 inches. Corresponding to the blanked-off hub is a core which extends cylindrically between the fans and tapers off upstream. The air passageway in the annular space thus provided has a constantly increasing area, so that the air flow reaches its minimum velocity just before entering the first fan. The air after passing the second fan escapes into the room.

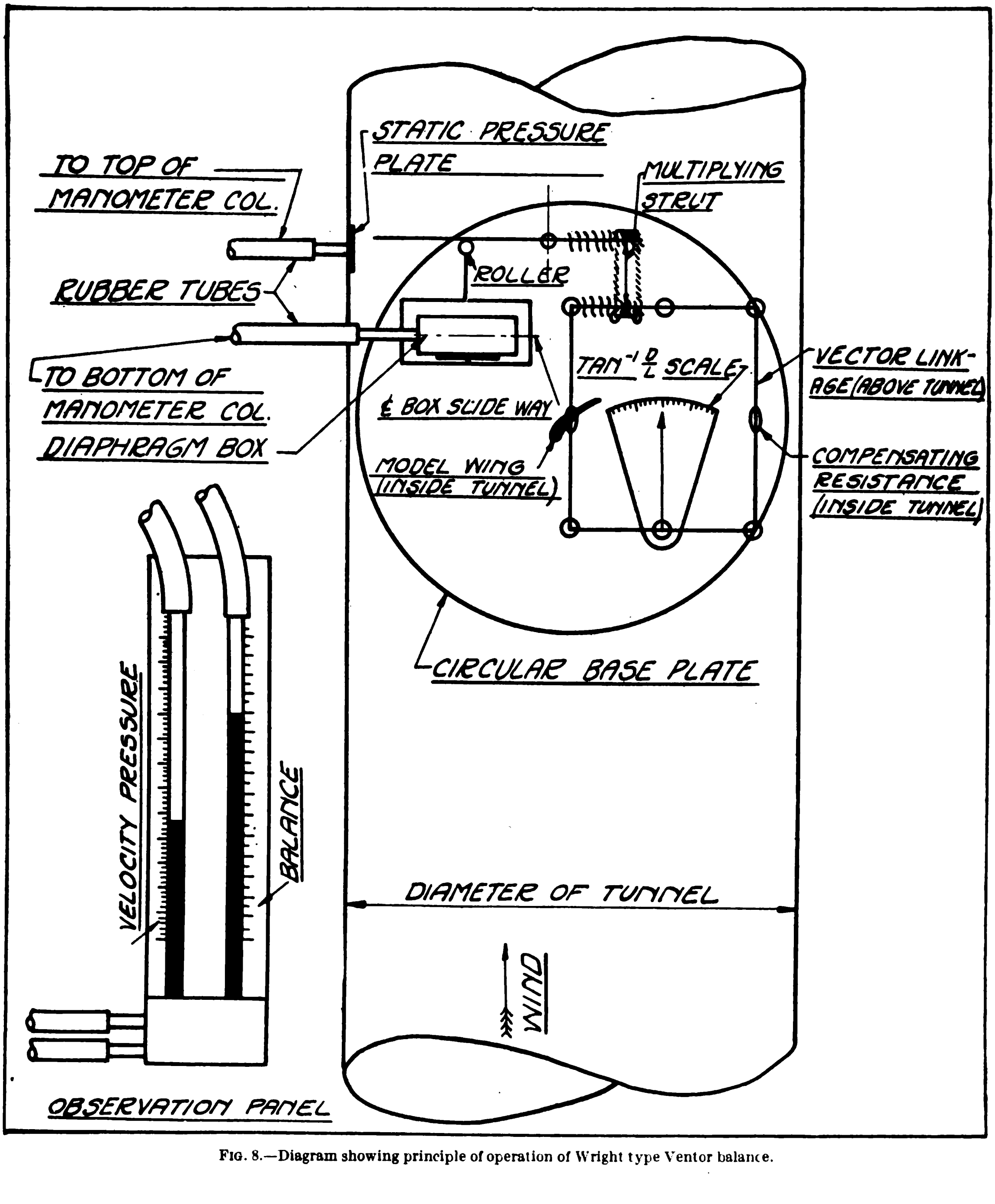


FIG. 8.—Diagram showing principle of operation of Wright type Ventor balance.

TANDEM FAN ARRANGEMENT.

The fans have been designed with the purpose of effecting a suitable compromise between the motive power, the diameter, and the revolutions per minute available for the project; they rotate in opposite directions, absorbing together over 600 horsepower at 900 revolutions per minute, and producing a throat velocity exceeding 200 revolutions per minute.

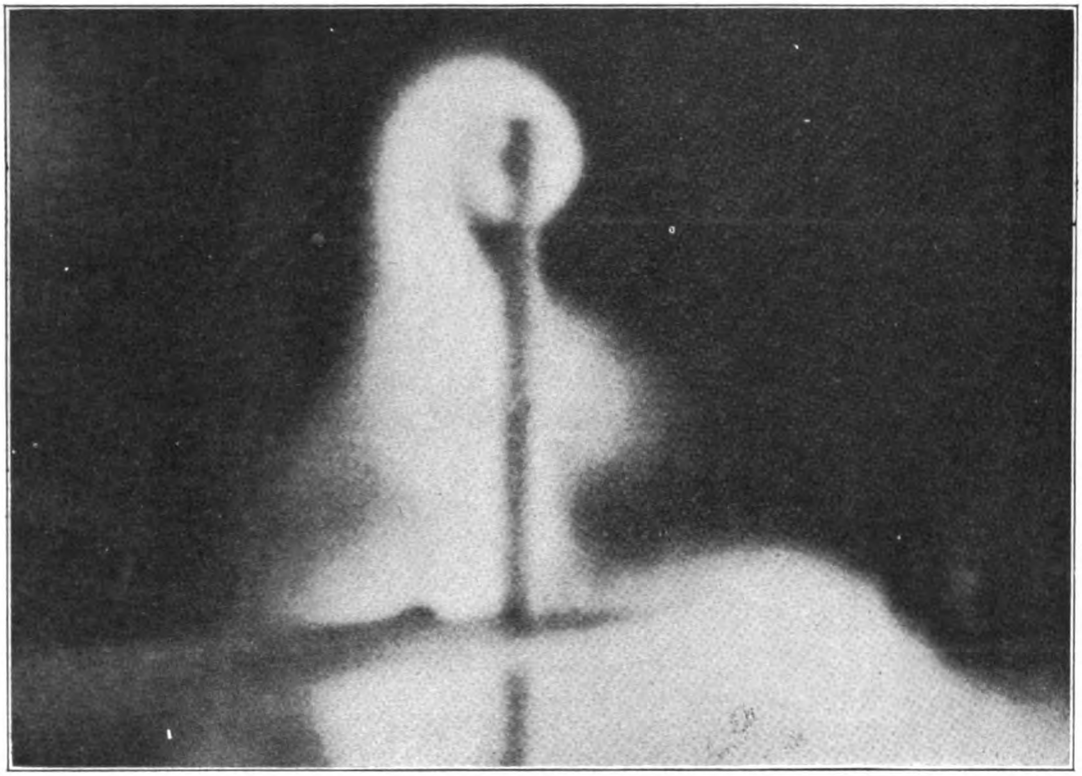


FIG. 9.—Plan view showing tip vortices trailing behind airplane wing, as visualized on model airfoil in high-speed wind tunnel.

MEASUREMENT OF VELOCITY.

Measurement of velocity is determined in the conventional manner by means of a flat plate orifice. For determination of the calibration and also for the determination of the pressure gradient along the axis, it is essential to make a longitudinal as well as a traverse map of the air pressures. By means of such traverses, we have found that a very good analysis of the air flow in any wind tunnel can be secured. For calibrating the various manometers on which pressures are read, two gauges are employed—one, the familiar Chattock micromanometer, the other an improvement on the Chattock, by name the Wahlen gauge.

WIND-TUNNEL SCOPE.

From the foregoing it is clear that the design of this tunnel combines features usually not available in a single tunnel. The feature of portability brings it about that the same tunnel may be used for high as well as low speed work. In routine model tests the lower speeds will be used and a honeycomb of the conventional type will be inserted at the throat in order to give the same air flow characteristics as have obtained in Air Service tests previously made by contract elsewhere. For high-speed work the Wright balance will be used.

HIGH-SPEED RESEARCH.

The new tunnel, while not large, offers a wider speed range than is usual. As a result it is expected that, in addition to routine tests, data will be secured on the speed and scale effects so important to the aircraft designer. The significance of a high-speed range has been demonstrated in the 14-inch tunnel built in 1918, using models the same size as the original models tested by the Wright brothers in 1901. The photograph of figure 9 is illustrative of the 1918 work and shows the character of air flow existing at critical velocity.

[redacted] ONLY

File D 72.1 / Davis/2

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | May 15, 1922 | No. 342

REPORT OF TEST OF DAVIS 3-INCH NONRECOIL CANNON MOUNTED IN MARTIN BOMBER

(ARMAMENT SECTION REPORT)

▽

Prepared by
H. A. Sutton, 1st Lieut., A. S.
Engineering Division, Air Service
McCook Field, Dayton, Ohio
December 19, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT OF TEST OF DAVIS 3-INCH NONRECOIL CANNON MOUNTED IN MARTIN BOMBER.

OBJECT OF TEST.

To determine the practicability of mounting a 3-inch Davis nonrecoil cannon on an airplane and firing it in the air.

DATE AND PLACE OF TEST.

This test was conducted at McCook Field, Dayton, Ohio, during November and December of 1921.

DESCRIPTION OF APPARATUS.

The gun as mounted for test on the ground is shown in Figures 1, 2, 3, and 4. The ammunition disassembled is shown in Figure 7. In this gun the recoil of the forward barrel is counterbalanced by that of the rear barrel in which a dummy charge is fired simultaneously with the projectile. Instead of having the breech closed by a breechblock it is left open, and a charge of fine shot which quickly dissipates is fired from the rear end. In this way the action is counterbalanced by reaction and the recoil effect is reduced to a minimum. The gun has but one powder chamber and one-half the powder may be regarded as propelling the forward projectile and the other half as propelling the dummy charge. The gun weighs about 180 pounds, and one round of ammunition weighs about 47½ pounds. The projectile weighs about 15 pounds. For air test the gun was mounted on a Martin bomber as shown in Figure 5.

DESCRIPTION OF TEST.

A test was made on the ground by firing into a pond at a depression angle of about 45 degrees. Two rounds were fired without any noticeable recoil. The gun was then mounted to fire into a sand butt, and one round was fired satisfactorily. An airplane wing section was then placed with its chord normal to the bore of the gun about 7 feet to the rear of the gun trunnions and with its leading edge about 5 feet from the axis of the gun barrel. The gun was fired horizontally to determine the blast effect on this wing and it was found that, with the wing moved to within 2 feet of the axis of the barrel the blast effect was not sufficient to damage the wing. It was decided that the gun could be safely fired from a mount in the nose of a Martin bomber, provided the gun was not fired at an angle which would place the barrel axis nearer than 2 feet to the wing. A yoke was made to mount this gun as shown in Figure 6.

Eight rounds were fired from an altitude of about 1,500 feet with satisfactory results.

CONCLUSIONS.

The blast effect or concussion was not harmful to the gunner but seriously inconvenienced the pilot. The gun is easily maneuvered since the wind pressure is balanced. The operation of loading and unloading is not particularly difficult.

For the purpose of determining the usefulness of a gun of this type it should be mounted on a gimbal joint to fire through the bottom of the fuselage, so the gunner will be protected from the wind.

For use as a bombardment gun this type is much better than the conventional type of cannon, due to the absence of recoil and low weight.

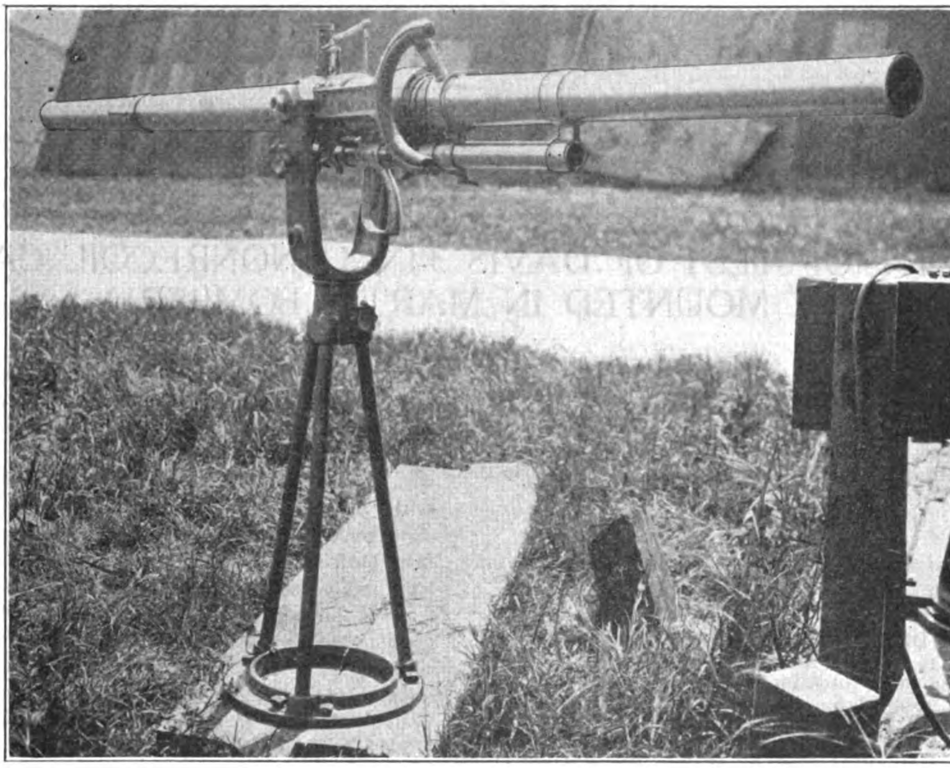


Fig. 1.—Davis 3-inch nonrecoil gun. Left rear view on ground test mount.

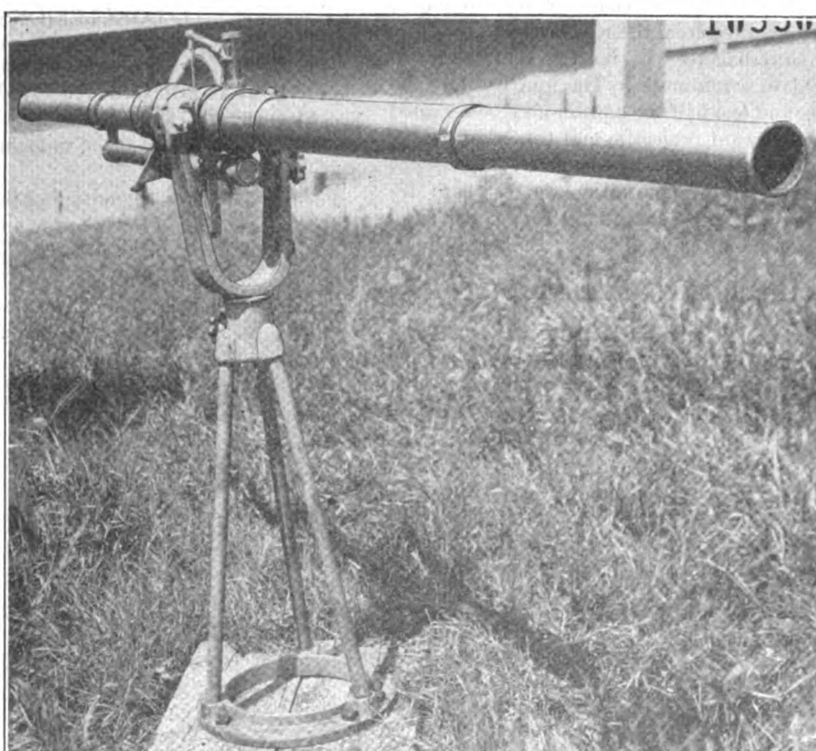


Fig. 2.—Davis 3-inch nonrecoil gun. Right front view on ground test mount.

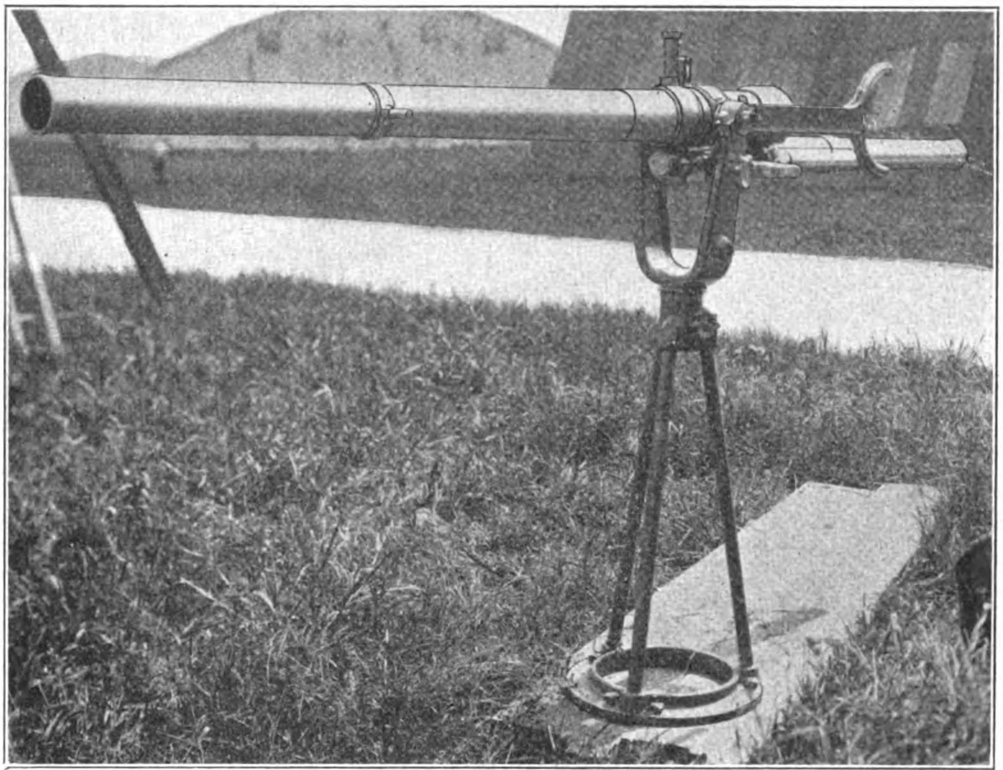


FIG. 3.—Davis 3-inch nonrecoil gun. Left front view on ground test mount.

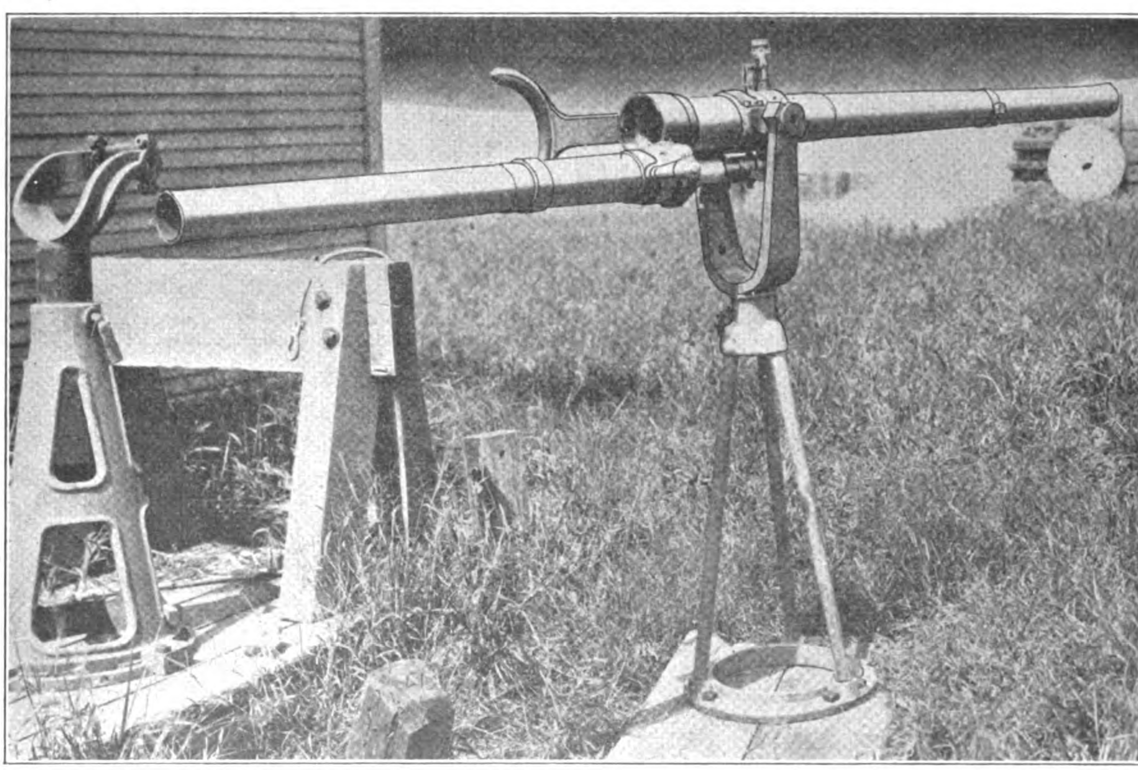


FIG. 4.—Davis 3-inch nonrecoil gun. Right rear view showing gun open.

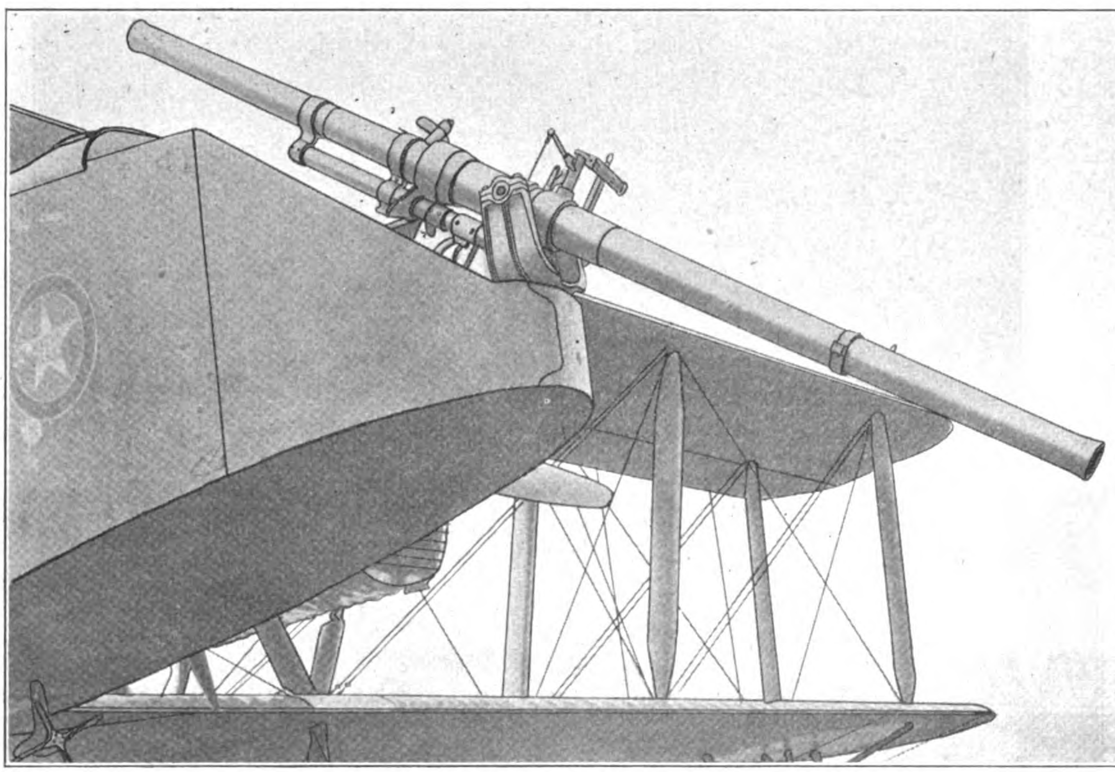


FIG. 5.—Davis 3-inch nonrecoil cannon mounted on Martin bomber.

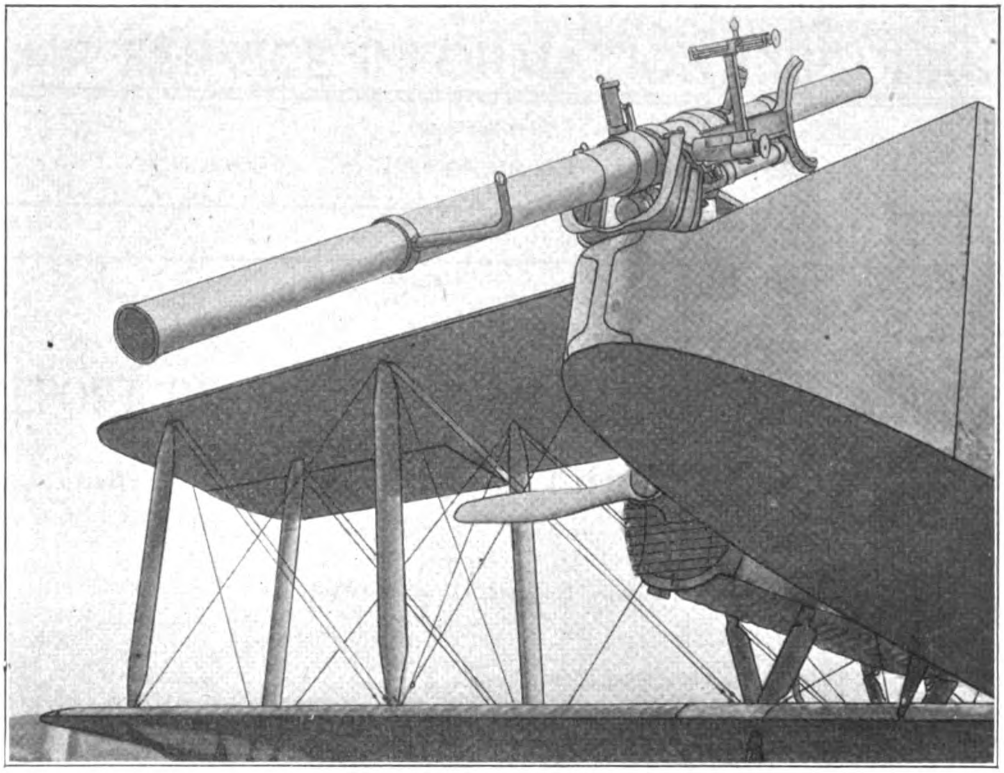


FIG. 6.—Davis 3-inch nonrecoil cannon mounted on Martin bomber.

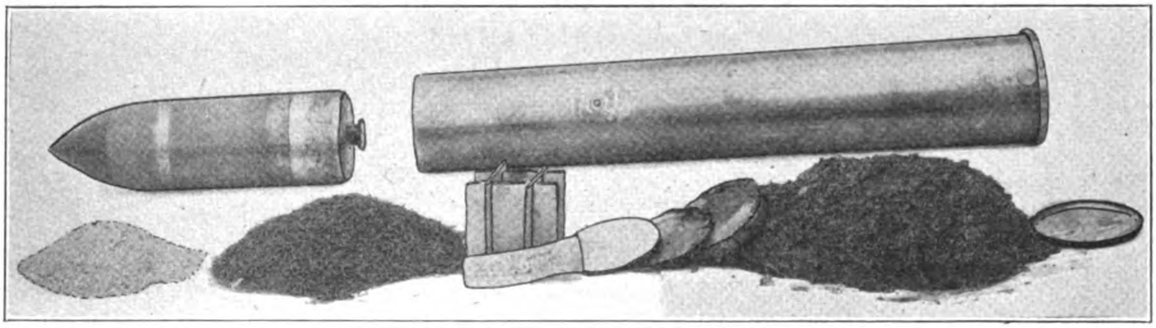


FIG. 7.—Davis 3-inch nonrecoil gun disassembled ammunition.

[redacted]

File D 52.41 /Wright/2 — *McCOOK FIELD REPORT, SERIAL No. 1840*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV — May 15, 1922 — No. 344

REPORT ON THE PERFORMANCE OF THE WRIGHT MODEL H-2 "SUPERFIGHTER" ENGINE

(POWER PLANT SECTION REPORT)

▽

Prepared by
W. W. Bishop, Jr., A. M. E.
Engineering Division, Air Service
McCook Field, Dayton, Ohio
January 16, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT ON THE PERFORMANCE OF THE WRIGHT MODEL H-2 "SUPERFIGHTER" ENGINE.

OBJECT OF TEST.

The test was conducted to determine the power output and fuel consumption of two Model H-2 Wright "Superfighter" engines and to compare their performance with that of the standard Model H Hispano-Suiza engine and a Model H Hispano-Suiza equipped with 6½ : 1 compression ratio.

SUMMARY OF RESULTS.

	Standard Hispano-Suiza Model H.[1]	Hispano-Suiza Model H 6½:1 compression.	Wright Model H-2(1).[2]	Wright Model H-2(2).[2]
Corrected brake horsepower, 1,800 revolutions per minute	326.0	352.0	373.0	359.0
Corrected brake horsepower, 2,000 revolutions per minute	358.5	378.0	404.0	388.0
Brake mean effective pressure pound per square inch 1,800 revolutions per minute	127.5	137.5	145.0	140.0
Brake mean effective pressure pound per square inch 2,000 revolutions per minute	126.5	132.5	141.5	136.5
Specific fuel consumption pound per horsepower hour 1,800 revolutions per minute	.525	.468	.455	.503
Specific fuel consumption pound per horsepower hour 2,000 revolutions per minute	.525	.477	.467	.506

[1] 5.3 : 1 compression ratio.
[2] Wright Model H-2 (1)—A. S. #94947, Wright Model H-2 (2)—A. S. #94895, "Superfighters."

CONCLUSIONS.

The two Wright Model H-2 engines tested showed an increase in brake horsepower over the Hispano-Suiza Model H of 9 and 14 per cent at 1,800 revolutions per minute with corresponding reductions in specific fuel consumption of 4 and 13 per cent, respectively. At 2,000 revolutions per minute the Model H-2 brake horsepowers were 8 and 13 per cent greater than that of the Model H and their specific fuel consumption 4 and 11 per cent lower, respectively.

DESCRIPTION.

The Wright Model H-2 engine is a redesign of the Hispano-Suiza Model H. (A description of the Model H engine is available in Engineering Division Report, Serial No. 798). Below are summarized the principal modifications constituting the Model H-2 characteristics. (For a complete statement as to the characteristics of the various models of the Wright series, see a letter from the chief engineer of the Wright Aeronautical Corporation to the Engineering Division, dated November 3, 1921.)

The cylinder head thickness has been increased 0.093 inch.

The magneto brackets are inclined at the engine end to permit the use of continuous engine bearers.

The oil return pipe is fitted at the side rather than under the lower half of the crank case.

Lightened pistons with 6½:1 compression ratio.

Weight 610 pounds.

The high compression H-2 engine, called the Wright "Superfighter" is manufactured by the Wright Aeronautical Corporation, Paterson, N. J. Photographs of the engine are included in figures 2, 3, and 4.

METHOD OF TEST.

The engines were mounted, successively, on the dynamometer (electric cradle) and the following runs made:

Two full-power check runs at 2,000 revolutions per minute. [1]

One full-power run, 1,500–2,100 revolutions per minute.

One friction horsepower run, 1,500–2,100 revolutions per minute.

The fuel used on the test consisted of a 50 per cent mixture by volume of benzol and aviation gasoline (War Department Specification No. 2-40). A description of the test apparatus and the methods of testing and computing results is available in Engineering Division Report No. 1507.

ANALYSIS.

Data from these runs are included in Tables 1 and 2. The curves in figure 1 include, for comparative purposes, the results of tests with the standard compression ratio Hispano-Suiza Model H engine, with the Hispano-Suiza Model H with 6½:1 compression ratio pistons, and with the two high compression Model H-2 engines. The tests of the Model H (standard compression ratio) and the special Model H with 6½:1 compression ratio are described in Engineering Division Reports Nos. 796 and 1710, respectively. The Model H engine with 6½:1 compression ratio pistons was converted, at McCook Field, by the Engineering Division from a standard Model H engine, by the installation of special pistons. No other changes were made. The power increase obtained over the low compression was not as great as could have been expected from tests in other types of engines with the same compression ratios and from tests on high compression Wright engines conducted at the plant of the Wright Aeronautical Corporation. For these reasons the laboratory tests were conducted on the Wright "Superfighter" engines.

The two Model H-2 engines developed, respectively, 373 and 359 horsepower at 1,800 revolutions per minute compared with the Model H horsepower of 326 at that speed. The difference was slightly less marked at 2,000 revolutions per minute, 404 and 388 horsepower for the H-2 engines against 358.5 for the Model H.

[1] With carburetor mixture control set successively for full rich, leanest mixture allowing of maximum power, and for full lean.

The corresponding specific fuel consumptions at 1,800 revolutions per minute were 0.455 and 0.503 pound per horsepower hour for the H-2 engine and 0.525 for the Model H. At 2,000 revolutions per minute the Model H-2 engines consumed 0.467 and 0.506 pound of fuel per horsepower-hour and the Model H 0.525 pound.

The brake mean effective pressure variations correspond with those in horsepower. At 1,800 revolutions per minute the Model H-2 engines developed 145 and 140 pounds per square inch brake mean effective pressure, while the Model H developed 127.5 pounds per square inch. At 2,000 revolutions per minute the Model H-2 engines developed 141.5 and 136.5 pounds per square inch, against 126.5 pounds per square inch for the Model H.

Both Wright H-2 "Superfighter" engines showed higher mean effective pressures and horsepowers than did the Model H Hispano-Suiza with the high compression pistons installed at McCook Field. In fuel consumption, however, one of the Model H-2 engines fell below and one exceeded the high compression Model H.

It should be added that the "Superfighter" and the McCook Field high compression Hispano-Suiza engines were equipped with "modified" NAD-6 carburetors. The standard Model H Hispano-Suiza engine (with 5.3 compression ratio), the performance of which was used as a basis of comparison for the other engines, was equipped with an unmodified NAD-6 carburetor. The modification consists in a special accelerating well which permits of the use of a "leaner" metering orifice without sacrificing good engine acceleration. As in all cases the fuel mixture was adjusted with the mixture control to the proper strength (for best power consistent with fuel economy), the difference in the size of the metering orifices did not affect the comparability of the test results.

TABLE 1.—*Model H-2 Engine, A. S. No. 94947.*

FULL POWER CHECK RUN.

R.p.m.	Actual.		Corrected.		Water.		Oil.			Carb. air temp. °F.	Man. vac. in. hg.	Mix. control position.	Fuel cons.	
	Brake load lbs.	B. h. p.	H. p.	B.m.e.p., lbs. per sq. in.	Temp. °F. In.	Temp. °F. Out.	Temp. °F. In.	Temp. °F. Out.	Press. lbs. per sq. in.				Lts. per hr.	Lbs. per hp. hr.
2,012	589.0	395.1	404.9	141.7	132 133	151 151	112 122	130 140	74 73	54 55	1.8 1.8	Full rich.	189.6	0.480
1,994	585.5	389.4	399.0	140.3	131 132	150 151	130 136	144 150	72 72	55 55	1.7 1.7	Best [1]	183.0	.470

Speed drops to 1400 r. p. m., brake load to 390 lbs., at full lean.

FULL POWER CHECK RUN.

R.p.m.	Brake load lbs.	B. h. p.	H. p.	B.m.e.p., lbs. per sq. in.	Water Temp. °F. In.	Water Temp. °F. Out.	Oil Temp. °F. In.	Oil Temp. °F. Out.	Oil Press. lbs. per sq. in.	Carb. air temp. °F.	Man. vac. in. hg.	Mix. control position.	Lts. per hr.	Lbs. per hp. hr.
2,026	588.5	397.5	407.2	141.5	132 130	150 148	102 110	130 138	70 70	56 56	1.7 1.7	Full rich.	191.4	0.482
2,002	585.5	390.7	400.3	140.3	132 134	150 152	111 104	140 138	70 70	57 57	1.7 1.7	Best [1]	187.0	.453

Irregular operation at full lean.

[1] Leanest setting allowing maximum power output.

Brake arm, 21 inches.
Kind of oil, Spec. No. 2-23 Grade B-3, 115-125 sec.
Fuel used spec. grav., 50 per cent benzol, 50 per cent domestic aviation gasoline.
Spark plugs, A. C.

Carbureter used, Stromberg NA-D6 Model.
Chokes, 1-13/16 inches.
Main jets, flow 74.5 pts. per hr.
Average barometer, 29.20 in. hg.
Date, October 12, 1921.

FULL POWER RUN.

R.p.m.	Actual.		Corrected.		Water.		Oil.			Carb. air temp. °F.	Man. vac. in. hg.	Mix. control position.	Fuel cons.	
	Brake load lbs.	B. h. p.	H. p.	B.m.e.p., lbs. per sq. in.	Temp. °F. In.	Temp. °F. Out.	Temp. °F. In.	Temp. °F. Out.	Press. lbs per sq. in.				Lbs. per hr.	Lbs. per hp. hr.
1,480	596.0	294.0	301.3	143.0	126	151	98	122	70	56	0.8	3.8	129.5	0.441
1,600	600.0	320.0	328.0	144.1	130	150	98	124	70	56	1.0	3.8	145.2	.450
1,670	604.0	336.5	345.0	145.2	130	149	98	126	68	56	1.2	3.8	154.9	.460
1,790	607.0	362.3	371.4	145.8	130	150	98	126	68	56	1.4	3.8	160.0	.442
1,890	599.0	377.5	387.0	143.9	130	149	98	130	68	56	1.6	3.8	172.7	.458
2,010	588.0	394.1	403.9	141.2	132	150	100	134	68	56	1.8	3.8	183.7	.466
2,100	578.0	404.6	414.7	138.8		Flash reading.			......	......	......	3.8	......	......

Table 1.—*Model H-2 Engine, A. S. No. 94947*—Continued.

FRICTION HORSEPOWER RUN.

R.p.m.	Brake load lbs.	F. h. p.	F.m.e.p. lbs. per sq. in.	Water. Temp. °F. In.	Water. Temp. °F. Out.	Oil. Temp. °F. In.	Oil. Temp. °F. Out.	Oil. Press. lbs. per sq. in.
1,500	59.0	29.5	13.8	150	152	94	114	72
1,600	67.5	36.0	15.8	150	152	96	114	71
1,700	76.0	43.1	17.8	150	150	96	116	70
1,800	77.5	46.5	18.2	150	150	96	120	68
1,900	80.0	50.7	18.8	149	150	98	122	68
2,000	84.0	56.0	19.7	148	150	98	124	68
2,100	83.0	58.1	19.5	......	......	......	......	......

Note—On the mixture control sector, position 2.75 is full rich, 6.75 full lean.

Brake arm, 21 inches.
Fuel used, spec. grav., 50 per cent benzol, 50 per cent domestic aviation gasoline.
Oil used, Spec., No. 2-23B Grade 3, 115-125 sec.
Spark plugs, A. C.

Carb. used, Stromberg NA-D6 Model.
Chokes, 1-13/16 inches.
Main jets flow, 74.5 pts. per hr.
Average barometer, 29.19 in. hg.
Date, October 12, 1921.

Table 2.—*Model H-2 Engine, A. S. No. 94895.*

FULL POWER CHECK RUN AT 2,000 R. P. M.

R.p.m.	Actual. Brake load lbs.	Actual. B. h. p.	Corrected. H. p.	Corrected. B.m.e.p. lbs. per sq. in.	Water. Temp °F. In	Water. Temp °F. Out	Oil. Temp. °F. In	Oil. Temp. °F. Out	Oil. Press. lbs per sq. in.	Carb. air temp. °F.	Man. vac. in. hg.	Mix. control position.[1]	Fuel cons. Lbs. per hr.	Fuel cons. Lbs. per hp. hr.
2,000	559.0	372.9	387.6	136.3	138	152	112	126	60	68	1.7	F. R.	204.6	0.549
2,012	557.0	373.8	388.5	135.8	132	148	126	140	60	68	1.7	Best	185.5	.497

Drops to 1,300 r. p. m., 400 lbs., brake load, at full lean.

FULL POWER RUN.

1,490	580.5	288.3	299.8	141.4	132	150	134	140	58	68	1.1	4.2	148.5	0.515
1,600	583.0	311.0	323.2	142.1	133	152	134	141	58	68	1.2	4.2	158.2	.509
1,680	583.0	326.8	339.6	142.1	130	148	134	141	60	68	1.3	4.2	162.1	.497
1,791	576.0	344.1	357.7	140.4	130	150	134	142	60	68	1.6	4.2	173.1	.503
1,893	564.0	356.2	370.3	137.7	132	150	136	144	60	70	1.8	4.2	184.8	.519
2,010	561.0	376.0	390.8	136.7	133	150	140	150	60	70	1.8	4.2	191.5	.510
2,090	549.0	382.6	397.7	133.8	133	150	142	154	60	70	2.1	4.2	194.0	.507

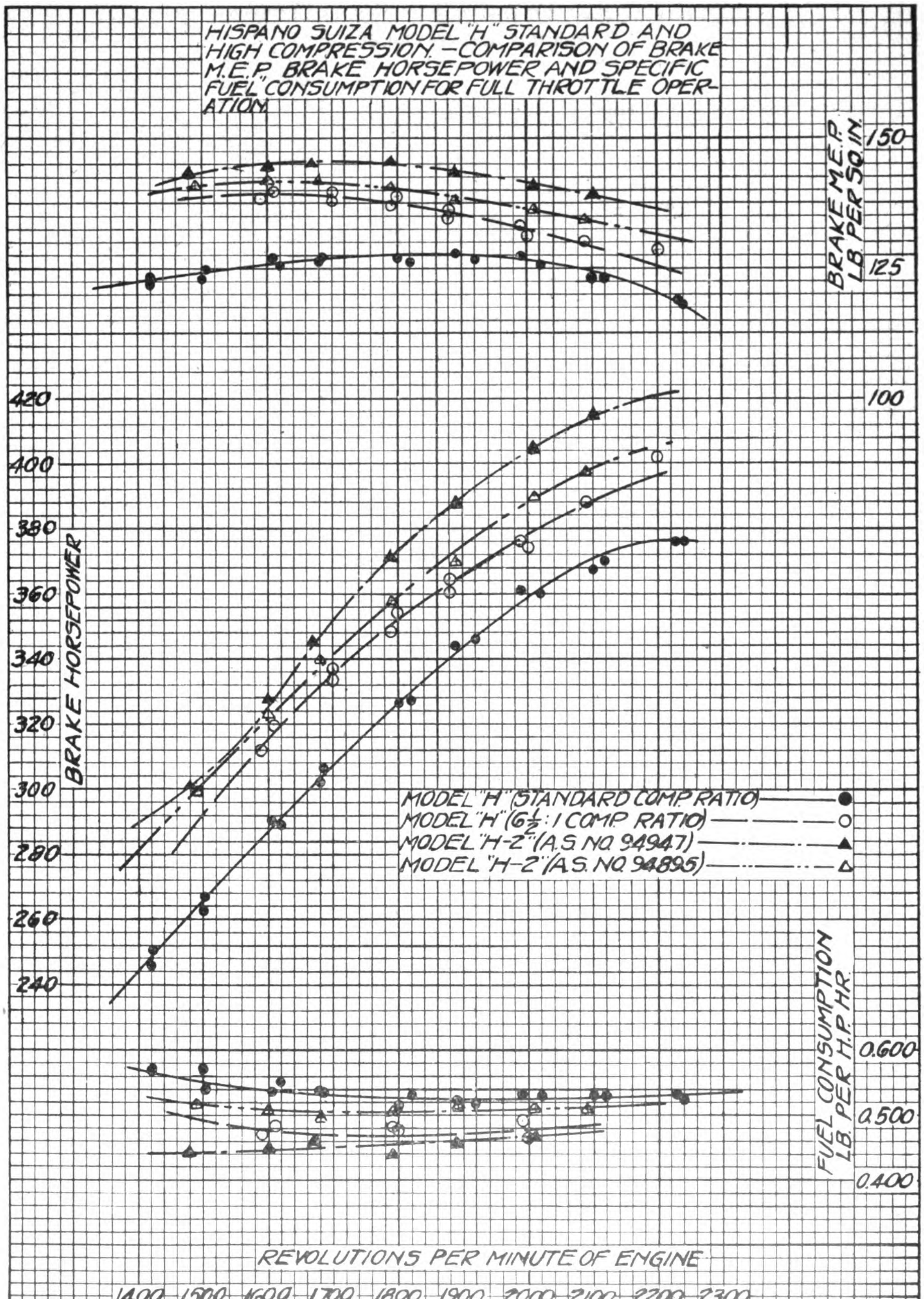
FRICTION HORSEPOWER RUN (THROTTLE WIDE OPEN).

R. p. m.	Brake load lbs.	F. h. p.	F.m.e.p. lbs. per sq. in.	Water. Temp. °F. In.	Water. Temp. °F. Out.	Oil. Temp. °F. In.	Oil. Temp. °F. Out.	Oil. Press. lbs. per sq. in.	Carb. air temp. °F.
1,500	60.5	30.3	14.2	148	150	130	130	58	70
1,600	68.0	36.3	16.0	148	149	130	131	60	70
1,700	77.0	43.7	18.1	149	150	128	134	60	70
1,800	79.0	47.4	18.5	149	150	128	140	60	70
1,900	81.0	51.3	19.0	150	150	128	142	60	70
2,000	82.5	55.0	19.4	150	150	132	138	60	70
2,100	82.0	57.4	19.2	151	151	134	138	60	70

[1] Note—On the mixture control sector, position 2.0 is full rich, 7.5 full lean, "Best" represents leanest setting allowing maximum power output.

Chokes, 1-13/16 inches.
Main jets, flow 76 pts. per hr.
Average barometer, 28.79 in. hg.
Date, October 7, 1921.
Brake arm, 21 inches.

Kind of oil, Spec. No. 2-23B, Grade 3, 115-125 sec.
Fuel used, 50% benzol, 50% domestic aviation gas.
Spark plugs, A. C.
Carb. used, Stromberg NA-D6 model.



HISPANO SUIZA MODEL "H" STANDARD AND HIGH COMPRESSION. - COMPARISON OF BRAKE M.E.P., BRAKE HORSEPOWER AND SPECIFIC FUEL CONSUMPTION FOR FULL THROTTLE OPERATION.
BRAKE M.E.P. LB. PER SQ. IN.
150
125
100
BRAKE HORSEPOWER
420
400
380
360
340
320
300
280
260
240
MODEL "H" (STANDARD COMP. RATIO)
MODEL "H" (6½ : 1 COMP. RATIO)
MODEL "H-2" (A.S. NO. 94947)
MODEL "H-2" (A.S. NO. 94895)
FUEL CONSUMPTION LB. PER H.P. HR.
0.600
0.500
0.400
REVOLUTIONS PER MINUTE OF ENGINE
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300

FIG. 1.

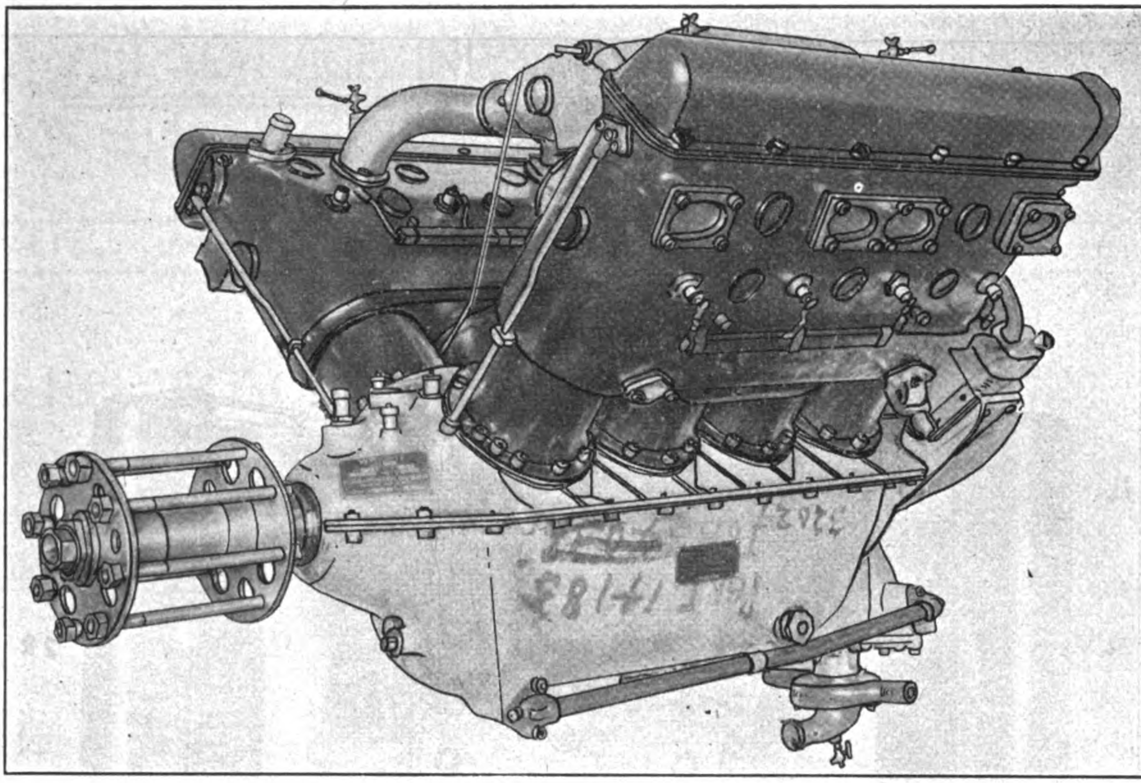


Fig. 2—Wright "Superfighter" Model H-2 Engine. Three-quarter front view.

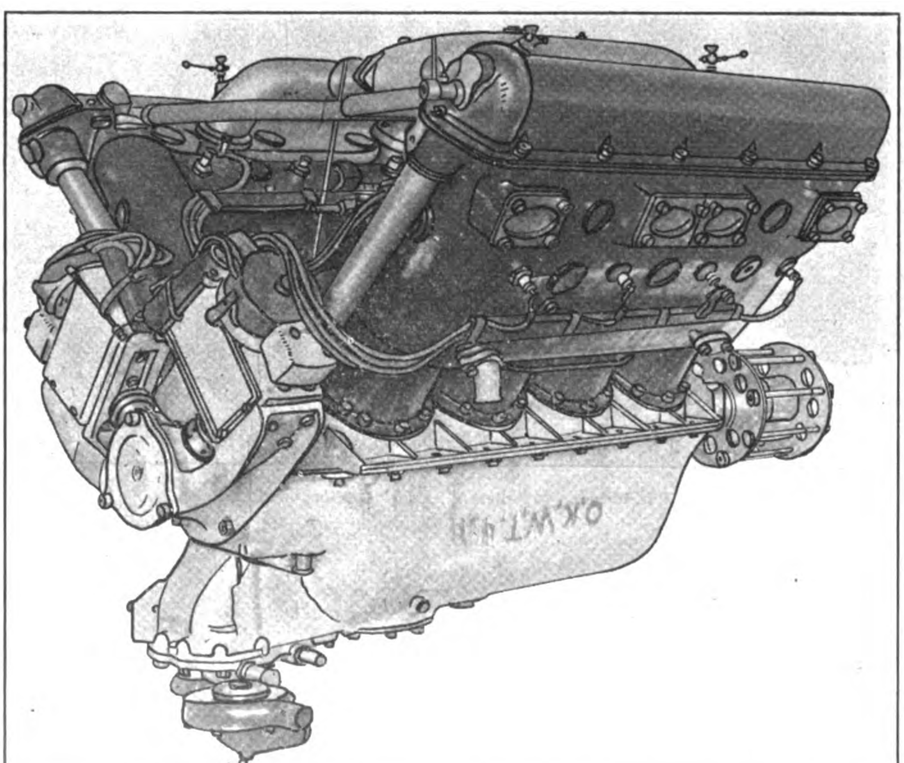


Fig. 3—Wright "Superfighter" Model H-2 Engine. Three-quarter rear view.

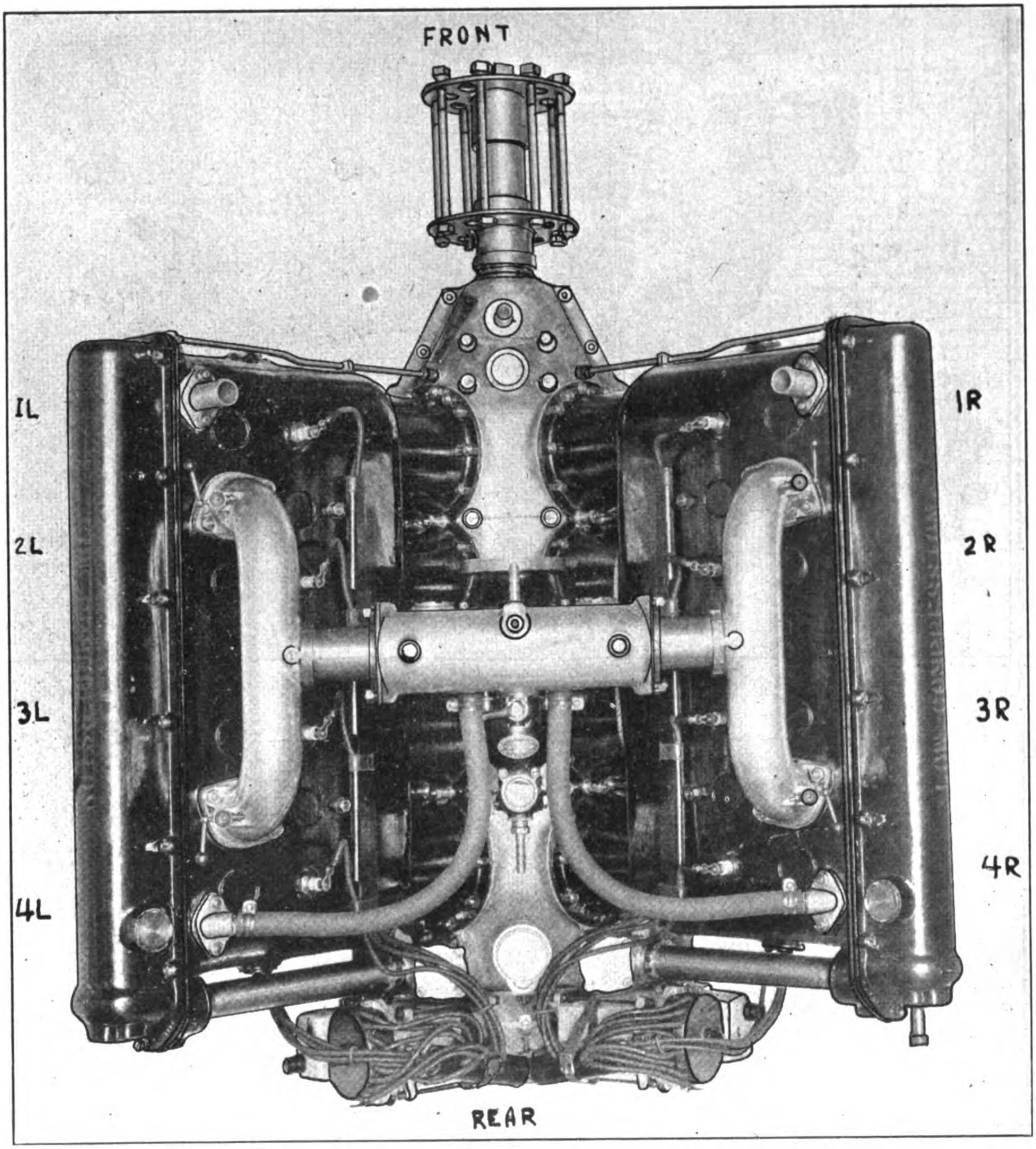


FIG. 4—Wright "Superfighter" Model H-2 Engine. Top view.

File D 52.419 / 103

McCOOK FIELD REPORT, SERIAL No. 1843

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | May 15, 1922 | No. 345

REPORT ON BLOWER USED IN TESTS OF AIR-COOLED CYLINDERS

(POWER PLANT SECTION REPORT)

△

Prepared by R. Insley, A. M. E.
Engineering Division, Air Service, McCook Field
Dayton, Ohio, January 24, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
5 CENTS PER COPY
SUBSCRIPTION PRICE, $1.25 PER YEAR

REPORT ON BLOWER USED IN TESTS OF AIR-COOLED CYLINDERS.

OBJECT OF TEST.

The purpose of the investigation was to determine the mean air velocities at the discharge of the blower used for cooling air-cooled cylinders on test and to study the effect on these velocities of varying the size of opening at the intake of the blower.

RESULTS.

The curves in Figure 1 show roughly the relation between orifice diameter and mean air velocity. It will be noted that the mean air velocity change with orifice diameter is almost a straight line variation, with the outside inlet alone open. With the larger orifice sizes the addition of the inside inlet opening adds noticeably to the blast velocity.

DESCRIPTION.

The blast for cooling air-cooled cylinders on the test stand (Engineering Division, McCook Field) is furnished by a 20-inch outlet Sirocco blower, manufactured by the American Fan and Blower Co. of Detroit, Mich. The blower is driven by a 100-horsepower induction motor and is fitted with a movable duct, directing the blast to the cylinder. An intake pipe from the roof is provided which permits the use of inside and outside air or outside air alone for cooling. Removal of one side of the intake "box" shown in Figure 4 admits air from the room to the blower. The cooling air velocity is regulated by orifice boards at the blower intake, adjusting the air flow by varying the size of the entrance orifice. Figures 3, 4, and 5 show the blower and driving motor.

METHOD OF TEST.

Air speed determinations were made with a combined Pitot and straight tube air speed indicator which had been calibrated previously with known air velocities in a wind tunnel. Readings were taken at points distributed over the mouth of the outlet duct as shown in the diagram, Figure 2.

With orifice plates of various diameter orifices inserted separately, runs were made for two determinations of mean velocity for each orifice, one with both inside and outside intakes open and one with the outside intake alone opened.

Because of their wide variance from the readings at the center of the duct and the slight effect on the cylinder cooling of the blast at these points, the outer readings, Nos. 1, 2, 3, 5, 6, and 7 have been disregarded in computing the mean air velocities. The others have been given equal weight in obtaining the average velocity.

RESULTS.

The curves in Figure 1 show the results of the average air velocity determinations, both with and without inside air admission to the blower. Data are tabulated in Tables 1 and 2. Because of the wide fluctuations of the air velocities in the duct, the readings, at best, are little better than approximations. The curves, however, show roughly the relation between orifice diameter and air speed and furnish a basis for estimating sizes of orifices to furnish any desired cooling air velocity. In general there seems to be very nearly a straight line relation between mean air velocity variation and the variation of orifice diameter, when the outside air inlet only is opened. With both inlets open, the straight line variation appears to hold true only with large orifice diameters. As the orifices grow smaller, however, the orifice resistance is sufficient to annul the influence of the change in intake area and the two curves converge. The highest point on the curves, 28-inch diameter, represents full open blower inlet and hence the highest possible blast velocity.

TABLE 1.—*Air speed (miles per hour).*

OUTSIDE INTAKE ONLY OPEN.

Station No.	28-inch orifice.	22-inch orifice.	21-inch orifice.	20-inch orifice.	17½-inch orifice.	17½-inch orifice.	14⅞-inch orifice.	12-inch orifice.
1	83.5	60.0	57.2	55.0	49.0	49.0	38.0	30.8
2	105.0	72.5	73.5	70.5	39.5	63.1	49.0	34.2
3	98.0	66.5	65.2	65.2	57.2	57.2	45.5	32.8
4	107.7	81.0	79.1	78.1	63.1	66.6	53.2	36.8
5	102.2	82.0	78.2	79.2	60.0	58.6	49.0	33.8
6	98.0	76.5	74.5	67.5	55.0	53.2	41.0	29.0
7	86.0	66.5	64.2	64.2	47.8	47.8	42.8	29.0
8	94.0	64.2	63.2	63.2	52.0	53.2	39.5	33.5
9	105.0	70.5	66.7	64.2	56.0	56.0	45.2	33.5
10	111.5	78.2	74.5	69.5	61.0	62.0	47.0	32.8
11	118.0	81.0	81.0	80.0	65.2	66.6	52.0	35.0
12	110.2	86.0	83.5	77.2	61.0	60.0	46.0	34.2
13	98.0	83.5	84.5	79.2	60.0	57.2	47.0	33.5
14	101.0	80.0	75.2	67.5	52.0	55.0	42.2	29.0
15	96.6	73.5	70.5	67.5	53.2	53.2	42.8	31.5
16	101.0	75.5	66.7	65.2	55.0	56.0	42.0	30.0
17	107.7	86.0	76.5	70.5	56.0	56.0	42.0	29.0

July 26–27, 1921.

TABLE 2.—*Air speed (miles per hour).*

OUTSIDE AND INSIDE INTAKES OPEN.

Station No.	28-inch orifice.	22-inch orifice.	20-inch orifice.	17½-inch orifice.
1	94.5	82.8	66.5	46.0
2	135.0	92.3	86.0	64.5
3	119.0	84.5	74.5	60.0
4	122.8	95.2	86.0	69.5
5	110.5	93.8	81.0	70.5
6	132.1	93.0	78.2	63.2
7	116.8	84.5	67.5	57.2
8	109.7	92.3	74.5	52.0
9	123.0	96.6	79.2	60.0
10	125.6	102.2	90.0	68.5
11	140.0	103.5	92.2	73.5
12	125.0	106.5	89.1	71.5
13	127.0	99.5	82.8	73.5
14	127.8	99.5	85.2	67.5
15	130.0	99.5	81.0	63.2
16	118.6	102.2	82.0	62.0
17	127.8	107.0	91.5	65.2

July 26–27, 1921.

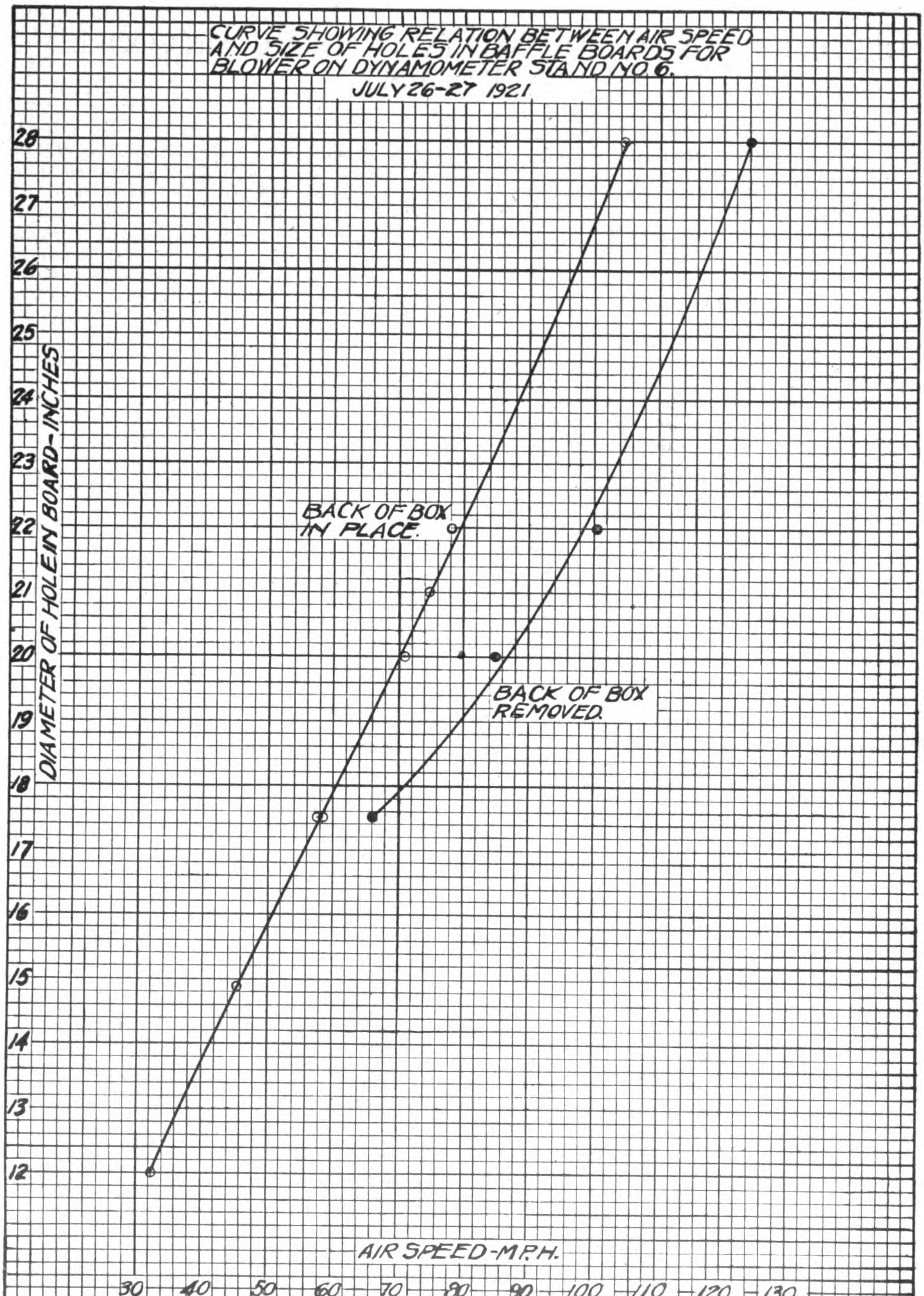

CURVE SHOWING RELATION BETWEEN AIR SPEED AND SIZE OF HOLES IN BAFFLE BOARDS FOR BLOWER ON DYNAMOMETER STAND NO. 6.
JULY 26-27 1921
DIAMETER OF HOLE IN BOARD-INCHES
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
BACK OF BOX IN PLACE.
BACK OF BOX REMOVED.
AIR SPEED-M.P.H.
30
40
50
60
70
80
90
100
110
120
130

FIGURE 1.

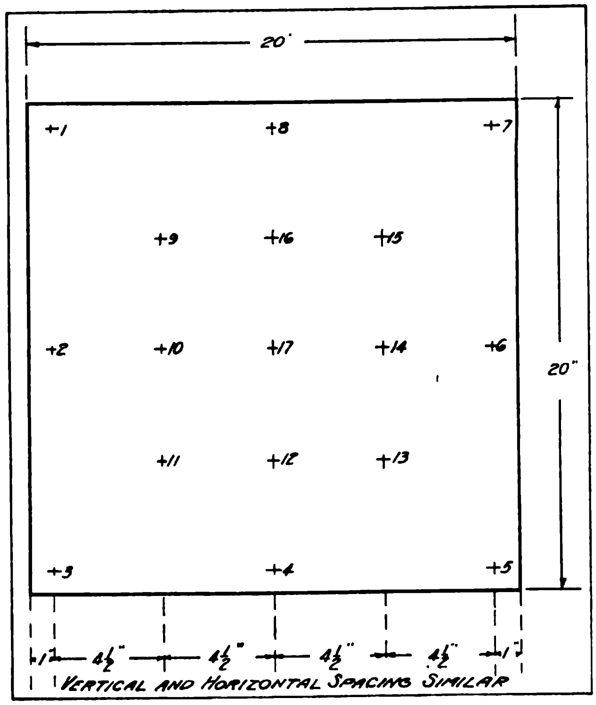


FIG. 2.—Location of air blast velocity readings in blower duct (facing blower outlet).

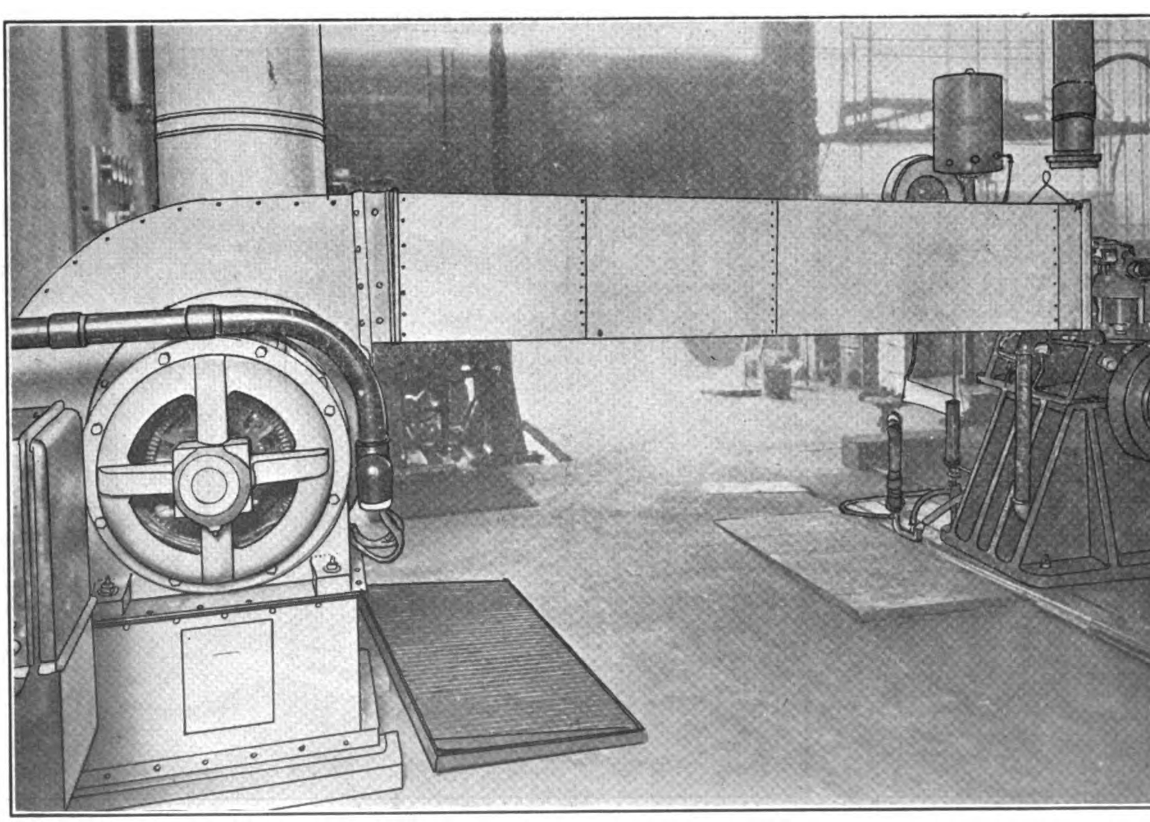


FIG. 3.—Blower, driving motor, and air duct.

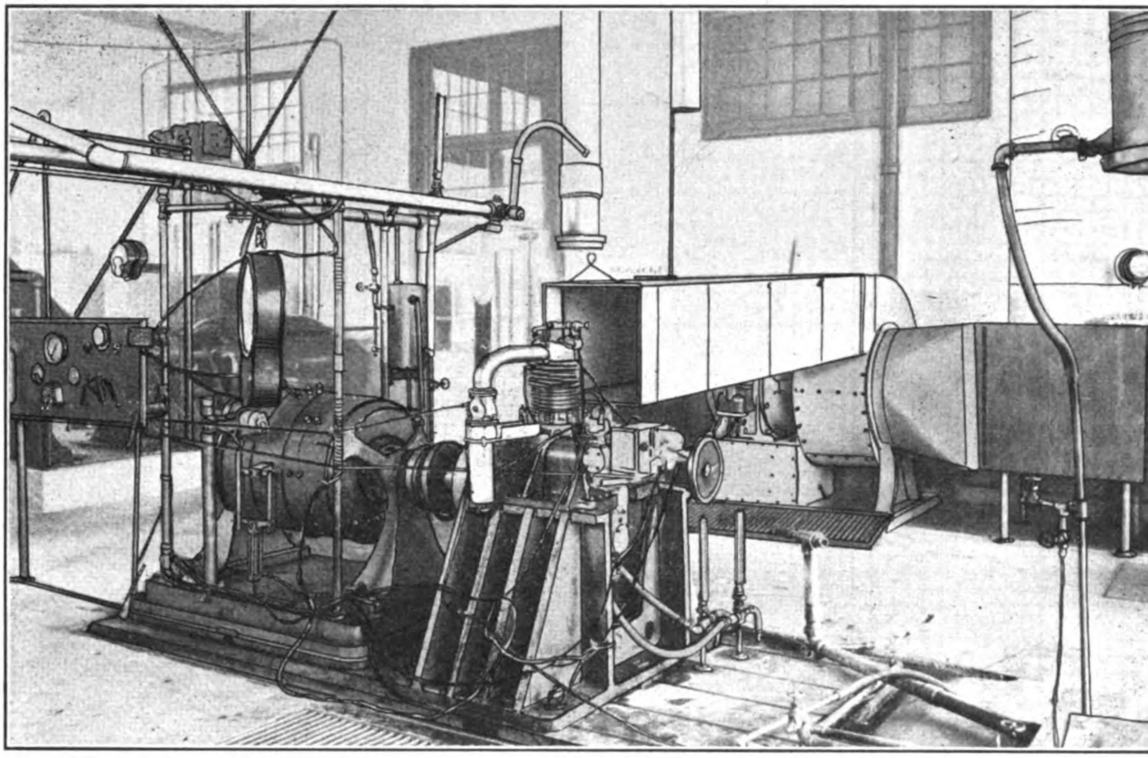


Fig. 4.—Air-cooled cylinder test stand, showing blower and air duct.

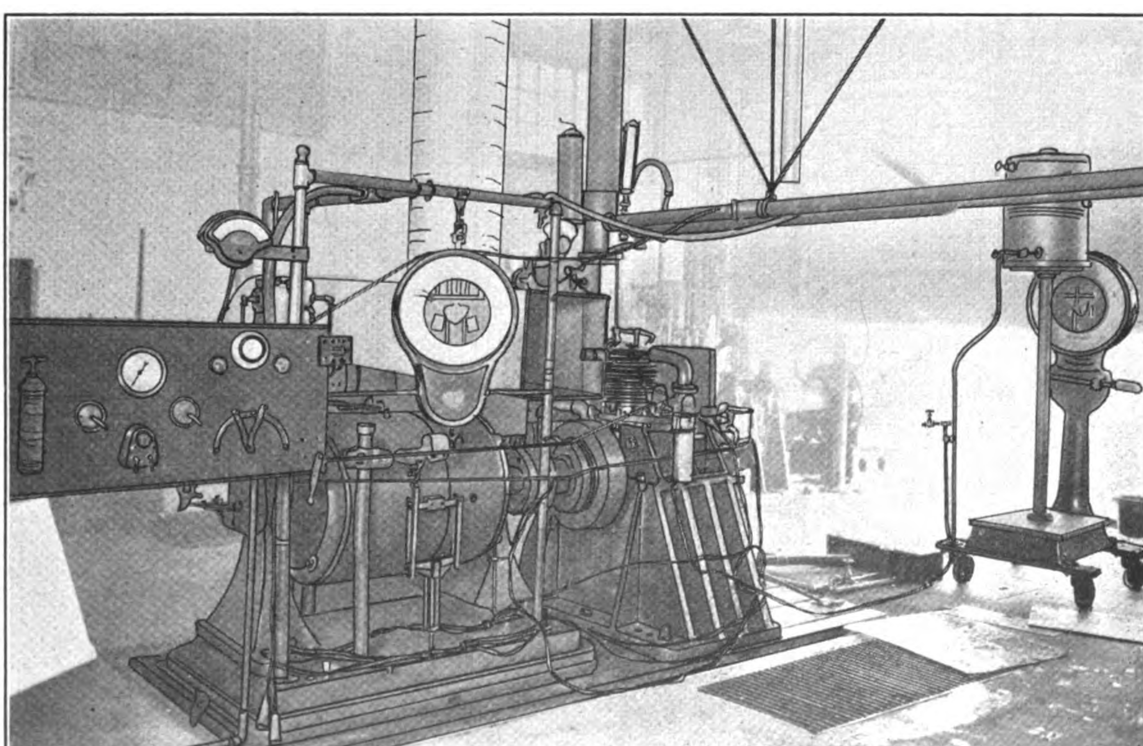


Fig. 5.—Air-cooled cylinder test stand.

File D 52.1/DH-4/125 McCOOK FIELD REPORT, SERIAL No. 1850

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV May 15, 1922 No. 346

FUEL CONSUMPTION TEST OF DH-4B WITH LIBERTY "12" ENGINE

(FLIGHT TEST REPORT No. 77)

▽

Prepared by Louis P. Moriarty, 1st Lieut. A. S.
Engineering Division, Air Service, McCook Field
Dayton, Ohio, January 25, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT ON FUEL CONSUMPTION TEST OF DH-4B WITH LIBERTY "12" ENGINE.

OBJECT OF TEST.

The object of this test was twofold:

(1) To determine the fuel consumption of the Liberty engine in a DH-4B at various speeds and altitudes.

(2) To determine the value of the Schroeder Econometer as a means of measuring fuel consumption.

SUMMARY OF RESULTS.

Full throttle consumption was as follows:

Altitude.	True air speed, miles per hour.	Revolutions per minute.	Consumption (gallons per hour).
2,000 feet	119	1,720	37.1
5,000 feet	116	1,710	34.0
8,000 feet	113	1,680	30.0

Consumption at various throttle settings is shown in Figure 1 and the accompanying table. A method of using Figure 1 to determine the most economical speed is shown in Figure 2.

Figure 3 gives a comparison of flow as determined by the Schroeder Econometer and by timing the consumption of a measured quantity of gasoline by stop watch. Considering the fact that the flow was very unsteady, the readings of the Econometer are surprisingly accurate. When tested in the laboratory, the instrument responds very quickly to changes in flow, its lag being less than one-fifth of a second, and after a change shows practically no tendency to oscillate about its new position. In flight there is considerable oscillation, due probably to actual variations in the flow.

RECOMMENDATIONS.

The instrument should read at least 25 per cent higher than the maximum average flow to be measured. A photographic means of recording its readings should be developed.

METHOD OF CONDUCTING TEST.

An auxiliary gasoline tank with glass gauge was installed in the rear cockpit, the piping and valves being so arranged that either the main tank or the auxiliary tank could be connected to the carburetor. The airplane was flown level at a given throttle setting until its motion became steady. The auxiliary tank was then connected, the main tank disconnected, and the time was taken by stop watch between marks on the glass gauge. Readings of airspeed and revolutions per minute and as many readings as possible of the econometer were taken while the auxiliary tank was being emptied. The econometer was connected between the auxiliary tank and the carburetor, thus giving a check upon its readings. At all times during these tests the mixture control was adjusted to give the best engine operation.

Table showing consumption at various altitudes.

ALTITUDE 2,000 FEET.

True air-speed (M. P. H.).	Revolutions per minute.	Consumption (gallons per hour).
119	[1] 1,720	37.1
110	1,610	26.4
100	1,485	20.2
90	1,375	17.2
80	1,285	15.2
70	1,200	13.7

ALTITUDE 5,000 FEET.

True air-speed (M. P. H.).	Revolutions per minute.	Consumption (gallons per hour).
116	[1] 1,710	34.0
110	1,650	27.5
100	1,520	20.7
90	1,425	17.5
80	1,345	15.4
75	1,300	14.6

ALTITUDE 8,000 FEET.

True air-speed (M. P. H.).	Revolutions per minute.	Consumption (gallons per hour).
113	[1] 1,680	30.0
110	1,650	25.8
100	1,515	19.8
90	1,430	17.2
80	1,365	15.6

[1] Full throttle.

DESCRIPTION OF ECONOMETER.

The operation of the Econometer is as follows:

The gasoline flows in at the bottom of a vertical slotted cylinder, forcing upward a light aluminum piston. The piston, as it rises, uncovers a portion of the slot, allowing the gasoline to flow out into the glass chamber which incloses the cylinder.

The pressure difference between the inside and the outside of the cylinder is constant, and depends only on the weight of the piston and the area of its circular cross section. The flow through the slot is therefore directly proportional to the area of slot uncovered, or conversely the area of slot uncovered is directly proportional to the flow. (This condition holds only when the slot is long in proportion to its width, which is the case except for very low rates of flow, when the piston approaches its lowest position.)

An indicating hand is attached to the piston and moves over a scale, reading length of slot uncovered in inches. For any particular liquid, these readings may be converted into units of volume flowing per unit of time. Due to variations in density and viscosity, the readings vary for different liquids. Variations in pressure, however, have no effect.

Photograph of instrument shown in Figure 4.

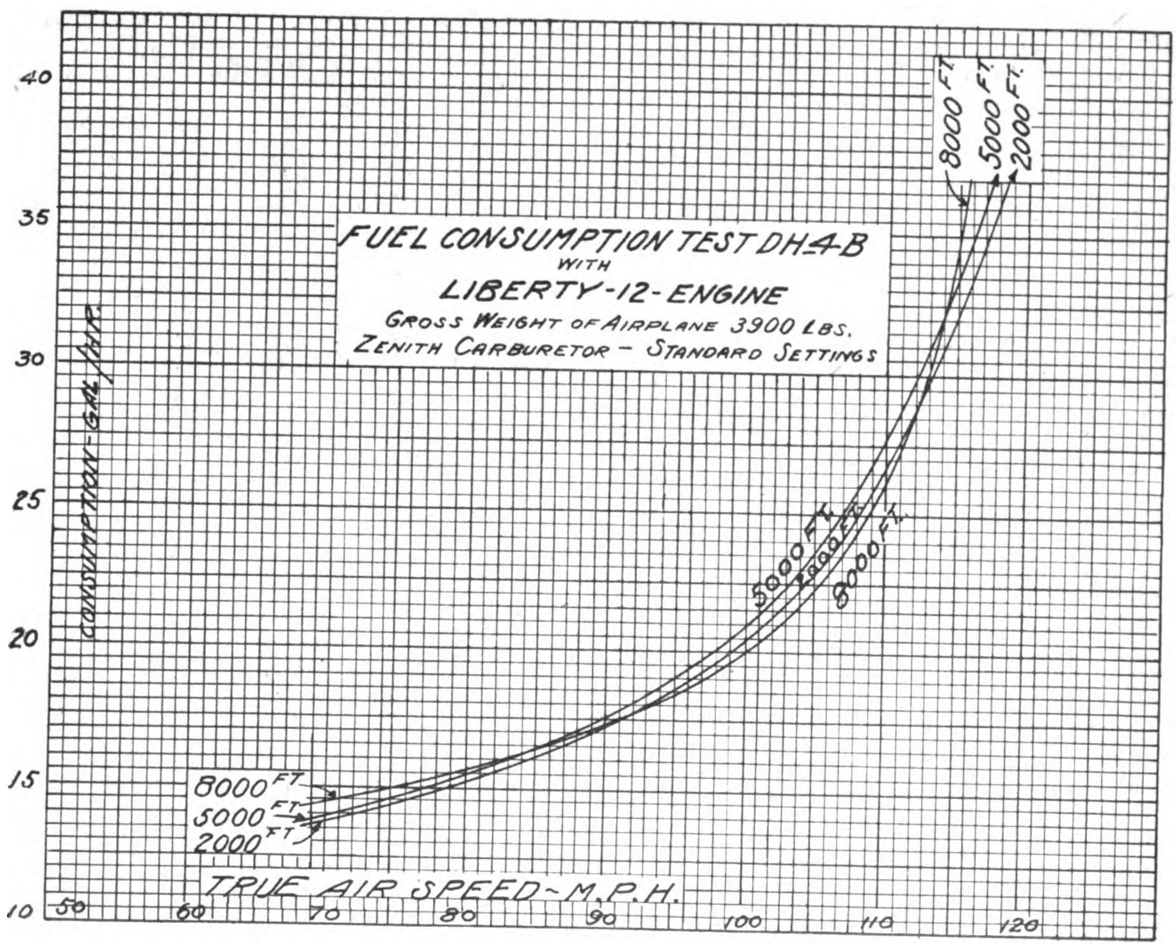

FUEL CONSUMPTION TEST DH-4-B
WITH
LIBERTY-12-ENGINE
GROSS WEIGHT OF AIRPLANE 3900 LBS.
ZENITH CARBURETOR - STANDARD SETTINGS
CONSUMPTION - GAL./H.P.
TRUE AIR SPEED ~ M.P.H.
8000 FT.
5000 FT.
2000 FT.
10
15
20
25
30
35
40
50
60
70
80
90
100
110
120

FIG. 1.

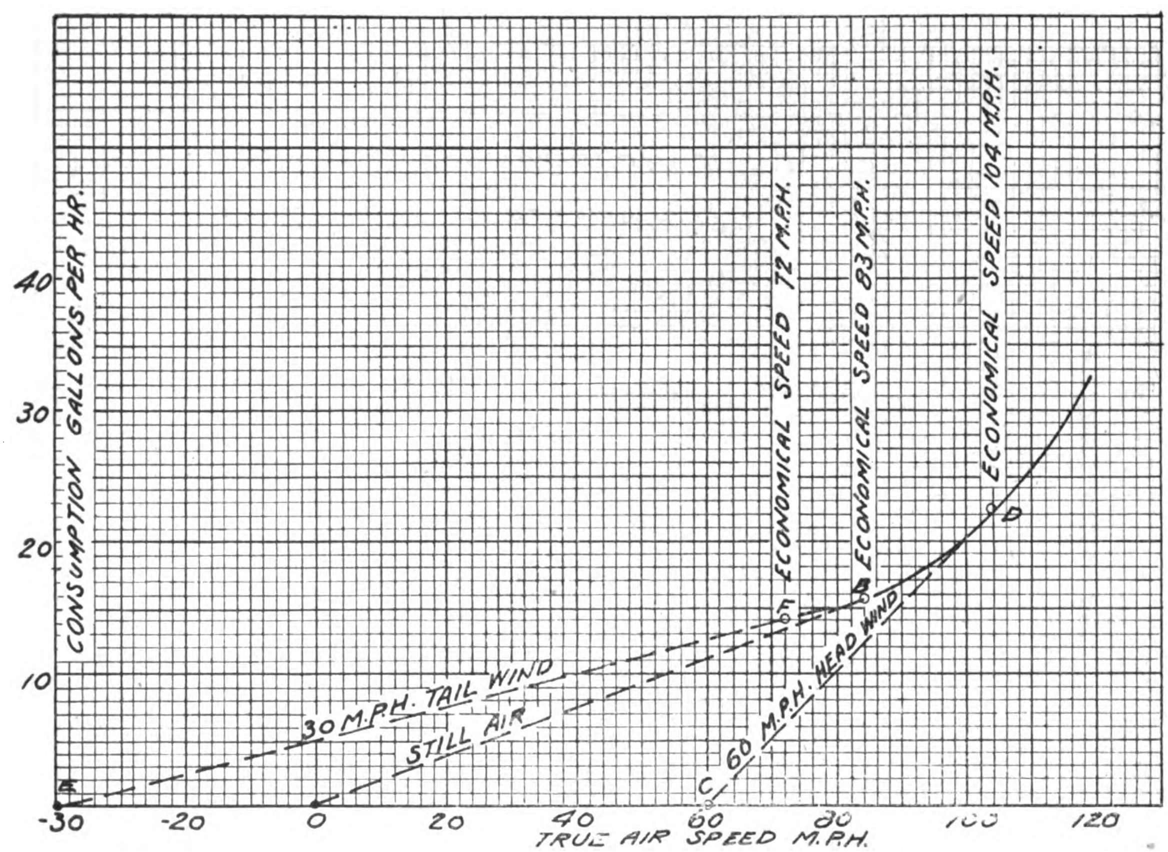


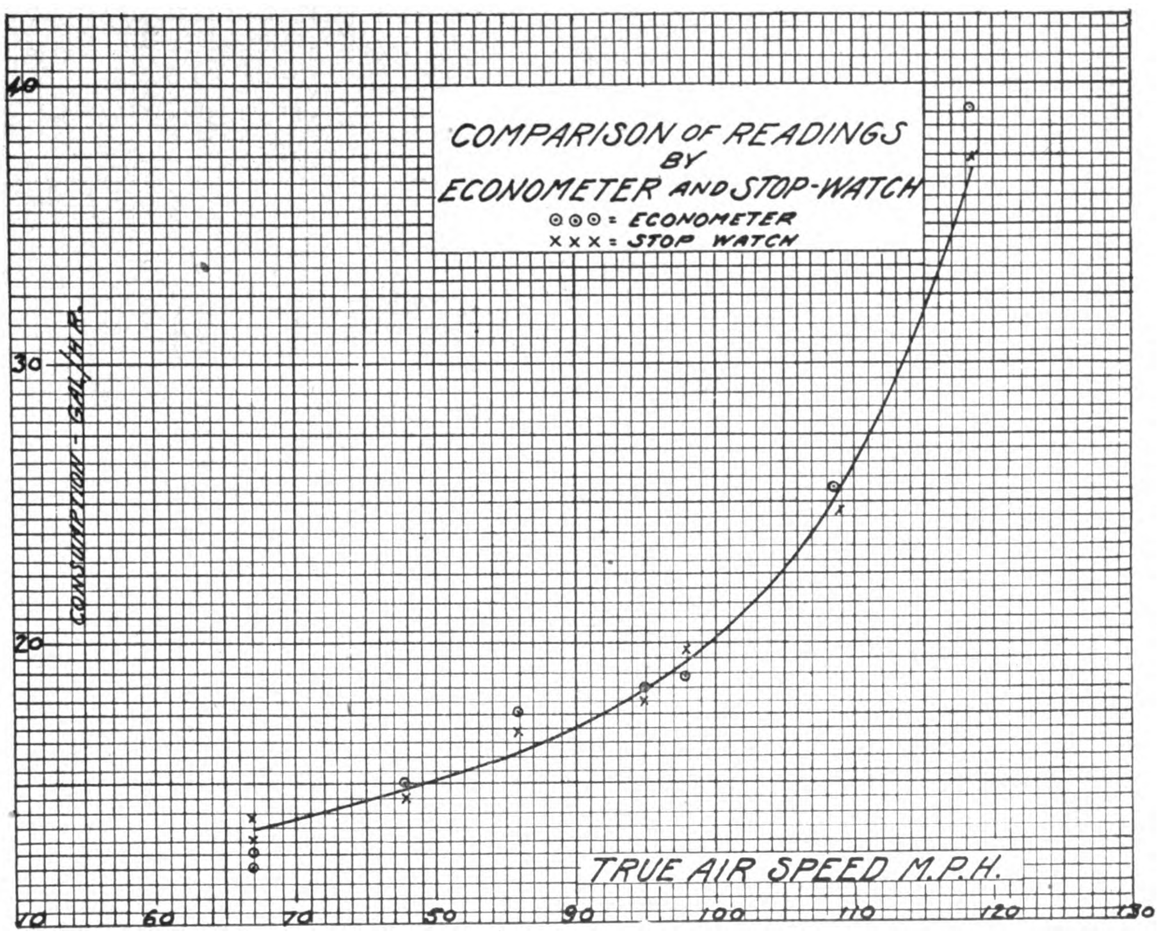
Fig. 2.

TO FIND MOST ECONOMICAL SPEED.

For still air, draw line OB through O and tangent to curve. Point of tangency gives most economical speed.

If airplane is traveling against the wind, lay off the velocity of the wind to the right of O and draw tangent from that point. (Line CD show 60 miles per hour head wind.)

If airplane is traveling with the wind, lay off velocity of the wind to the left of O. (Line EF shows 30 mi'es per hour tail wind.)


COMPARISON OF READINGS
BY
ECONOMETER AND STOP-WATCH
⊙⊙⊙ = ECONOMETER
XXX = STOP WATCH
CONSUMPTION - GAL/H.R.
40
30
20
TRUE AIR SPEED M.P.H.
70
60
70
50
90
100
110
120
130

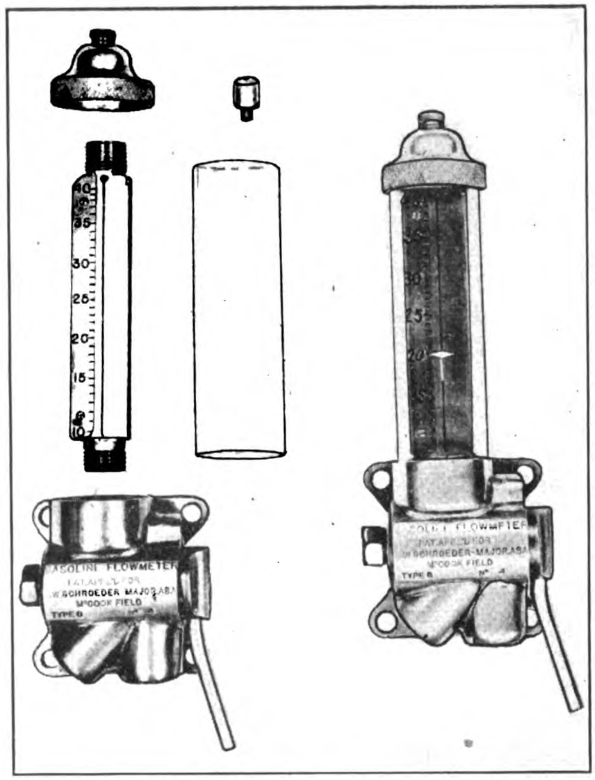

FLOWMETER
SCHROEDER MAJOR
McCOOK FIELD
FLOWMETER
McCOOK FIELD

FIG. 4.

File D 52.1 / Vought / 3

McCOOK FIELD REPORT, SERIAL No. 1817

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | June 1, 1922 | No. 352

PERFORMANCE TEST OF NAVY VOUGHT TYPE XV EQUIPPED WITH WRIGHT MODEL E-2 ENGINE

(PERFORMANCE TEST REPORT No. 73)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
November 1, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

PERFORMANCE TEST OF NAVY VOUGHT TYPE XV EQUIPPED WITH WRIGHT MODEL E-2 ENGINE.

OFFICIAL PERFORMANCE TEST—SUMMARY OF RESULTS.

November 1, 1921.

Airplane: Navy Vought.
No.: P-204.
Type: XV.
Engine: Wright, Model E-2.
Propeller: X-6233, A. S. No. 60340.
Equipped as: Advanced training.
Weight empty (including water): 1,569 pounds.
Armament and equipment: 140 pounds.
Crew: 360 pounds.
Gasoline: 177.5 pounds.
Oil: 22.5 pounds.
Weight loaded: 2,269 pounds.
Weight, square foot: 7.96 (285 square foot R. A. F.-15).
Weight, horsepower: 12.2 (194 horsepower at 1,830 revolutions per minute).
Fineness: 113.5 Ae-5.7.

Standard altitude in feet.	Climb.				Speed.		
	Time in min.	R. P. M.	Rate ft./min.	Flow gal./hr.	M.P.H.	R. P. M.	Flow gal./hr.
0	....	1,620	1,070	....	124	1,830	....
6,500	7.3	1,610	735	....	122	1,790	....
10,000	12.6	1,605	565	....	120	1,760	....
15,000	24.4	1,585	315	....	113	1,690	....
20,000	....	....	....	....	....	....	....
25,000	....	....	....	....	....	....	....
[1] 19,200	48.5	1,565	100	....	102	1,615	....
[2] 21,200	....	1,550	0	....	84.5	1,550	....

[1] Service ceiling. [2] Absolute ceiling.

Endurance, full throttle at 10,000 feet (including climb): 2 hours 28 minutes.

Minimum speed at sea-level (lowest throttle): 60 miles per hour.

Landing speed:

PILOT'S OBSERVATIONS.

FLYING QUALITIES.

Taxi-ing.—Somewhat difficult to taxi in strong wind.

Take off.—Responds well to controls during run. Takes off easily with short run.

Landing.—Lands easily and slowly. Has slight tendency to spin on ground, which can usually be corrected without use of the throttle. Has flat gliding angle. Will float for considerable distance if brought in too fast.

Stability.—Lateral, very good. Longitudinal, stable throughout range of speeds and throttle settings; stable on glide. At stalling speed tends to fall into spin.

Maneuverability.—Ease of control, good. Response to control, rapid. Handles easily in all maneuvers. Holds steep banks well and turns sharply, but will fall into spin if pulled in too tight. Spins rapidly, but recovers quickly. Can not be rolled with safety, as leading edges of wings are weak.

VISIBILITY.

Rear seat, good in all directions.

Front seat, poor for combat, formation flying, or cross-country flying, fair for landing.

MAINTENANCE.

Airplane is excellent from point of view of maintenance. Two machines of this type were flown, one for 50 hours and the other for 100 hours, without any important troubles being experienced. Both of these airplanes were in commission practically all of the time.

The engine mounting is very good. All engine accessories are easily reached. Very little vibration is noticeable.

SUMMARY.

The flying qualities of this airplane are very good, its maintenance is simple, and, in general, it is very efficient. It is too sensitive on the controls for preliminary training, but would be a good machine for advanced training.

DISTRIBUTION OF WEIGHTS.

[By pounds.]

Weight empty (with water): 1,569.
Armament and equipment: 140.
Crew: 360.
Gasoline: 177.5.
Oil: 22.5.
Weight loaded: 2,269.
Weight on front wheels (tail skid on ground): 1,983.
Weight on tail skid (tail skid on ground): 286.
Weight on front wheels (flying position): 2,087.
Weight on tail skid (flying position): 182.
Center of gravity (distance from wheels in flying position): 15.5 inches. Distance center line of axle to point of support of tail skid: 16 feet 1 inch.
Provisions for special equipment not carried during test.

103758—22

DESCRIPTION OF AIRPLANE.

DIMENSIONS.

Overall span: 34 feet 5½ inches
Overall length: 24 feet 8½ inches.
Overall height: 8 feet 4½ inches.
Height at hub of propeller above ground:
In flying position: 4 feet 2 inches.
At rest: 5 feet 10⅜ inches.

AIRPLANES.

Sweepback: None.
Dihedral: 1 degree 15 minutes.
Stagger: 11¼ inches.
Total area including ailerons: 274.39 square feet.
Gap: 4 feet 8 inches.

UPPER PLANE.

Including center section.

Span: 34 feet 5½ inches.
Chord: 4 feet 7 inches.
Area, with ailerons: 143.07.
Incidence: 1 degree 45 minutes.

LOWER PLANE.

Span: 34 feet 2½ inches.
Chord: 4 feet 7 inches.
Area: 131.32 square feet.
Incidence: 2 degrees 15 minutes.

AILERONS OR FLAPS.

Number: 4.
Arrangement: 2 on upper and 2 on lower wing.
Upper length: 6 feet 8 inches.
Upper chord: 1 foot 6 inches.
Upper area: 2 at 10.01=20.02 square feet.
Lower length: 6 feet 8 inches.
Lower chord: 1 foot 6 inches.
Lower area: 2 at 10.01 square feet=20.02 square feet.
Total area: 40.04 square feet.
Distance from center of ailerons to longitudinal axis of airplane: 13 feet 10 inches.

CENTER SECTION.

Area: 15.08 square feet.
Dimensions: 4 feet 7 inches by 4 feet 7 inches.
Contents: None.

STABILIZER.

Area: 9.45 square feet.
Setting: Zero with thrust line.

ELEVATOR.

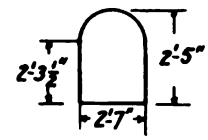
Area: 15 square feet.
Distance from leading edge of elevator to center of gravity of airplane: 16 feet 1$\frac{13}{16}$ inches.

RUDDER.

Area: 7.2 square feet.
Distance from leading edge of rudder to center of gravity of airplane: 16 feet 4$\frac{3}{16}$ inches.

FUSELAGE.

Max. cross section shape.



Max. cross section area: 2 feet 7 inches.
Max. cross section dimension: 2 feet 5 inches by 2 feet 7 inches.
Distance of maximum section from leading edge, lower plane: 1 foot 8½ inches.

LANDING GEAR.

Number of wheels: 2.
Tread: (tires 26 by 4), 5 feet 2 inches.
Shock absorbing system: Rubber cord.
Braking device: Tail skid.
Wheels ahead of center of gravity, 15.5 inches.

FIN.

Area: 2 square feet.

DESCRIPTION OF POWER PLANT.

ENGINE.

Make: Wright E-2.
Factory No.: ——.
A. S. No.: 95029.
Type: V—8 cylinder.
Number in plane: 1.
Location: Nose of fuselage.
Rated horsepower: 190.
Rated revolutions per minute: 1,800.
Bore: 4.724-inch (120 mm.).
Stroke: 5.118-inch (130 mm.).
Compression ratio: 5.5: 1.
Weight, dry: 476.
Gas consumption: 0.493 pound per horsepower hour.
Oil consumption: 0.0193 pound per horsepower hour.
Weight of water in engine: 44 pounds.

IGNITION.

Battery or magneto: Magneto.
Make: Dixie No. 800.
Number: 2.
Advance, degrees: 25.
Gas interrupter: 0.018.
Distributor: None.
Plugs, make: A. C.
Type: Metal body, porcelain insulator.
Gap: 0.020.

CARBURETORS.

Make: Stromberg.
Type: NAD 4.
Number: 1.
Main setting jet: 42 drill size.
Choke: 1½-inch.
Compensator body metering nozzle: No. 30.
Gas drains: From intake to copper tube outside of fuselage.
Air intake: Through stack in slip stream.
Altitude control: Back suction.

RADIATORS.

Make: Rex Radiator Mfg. Co.
Type: Honeycomb.[1]
Number: 1.
Position: Nose.
Frontal area: 3.27 square feet.
Core depth: 4 inches.
Length: 33 inches.
Width: 25 inches.
Radiator surface: 130 square feet.
Temp. ajt.: Shutters.
Water capacity: 5.5 gallons.
Flow, gallons per minute: 40 gallons per minute at 2.5 pounds pressure. Cools on temperature diff. of 60° C., which allows full climb without boiling when the ground temperature is approx. 32° C, 90° F.
Thermometers, make: Boyce Model O.
Weight, pounds: 65.
Water capacity of whole system: 10 gallons.

EXHAUST PIPES.

Description: Short stacks, leading into manifolds, one on each side.

LUBRICATION.

Capacity oil tank: 3 U. S. gallons.
Dimensions oil tank: ———.

[1] See drawing No. 048842-5.

Oil used (brand): Liberty.
Oil pressure: 53 pounds per square foot.
Temperature: 140° F.
Type pump: Gear.
Wet or dry sump: Dry.
If wet, capacity: ———.
Description lubrication system: Standard, pressure feed.

FUEL SYSTEM.

No. of tanks: 2, Main.
Location: One, rear of engine; one under rear seat.
Capacity: Both tanks, 177.5 pounds. One tank 20 gallons; one tank 10 gallons.
Description of fuel supply system: Air pressure; selective as to either or both tanks.

ENGINE CONTROL.

Description: Rod and lever.

PROPELLER.

Make: Engineering Division.
Number blades: 2.
Diameter: 8 feet 6 inches R. H.
Pitch: 6.04 feet.
Tips: Terne date.
Clearance: ———.
Manufacturer's No. ———.
A. S. No.: x-60340.

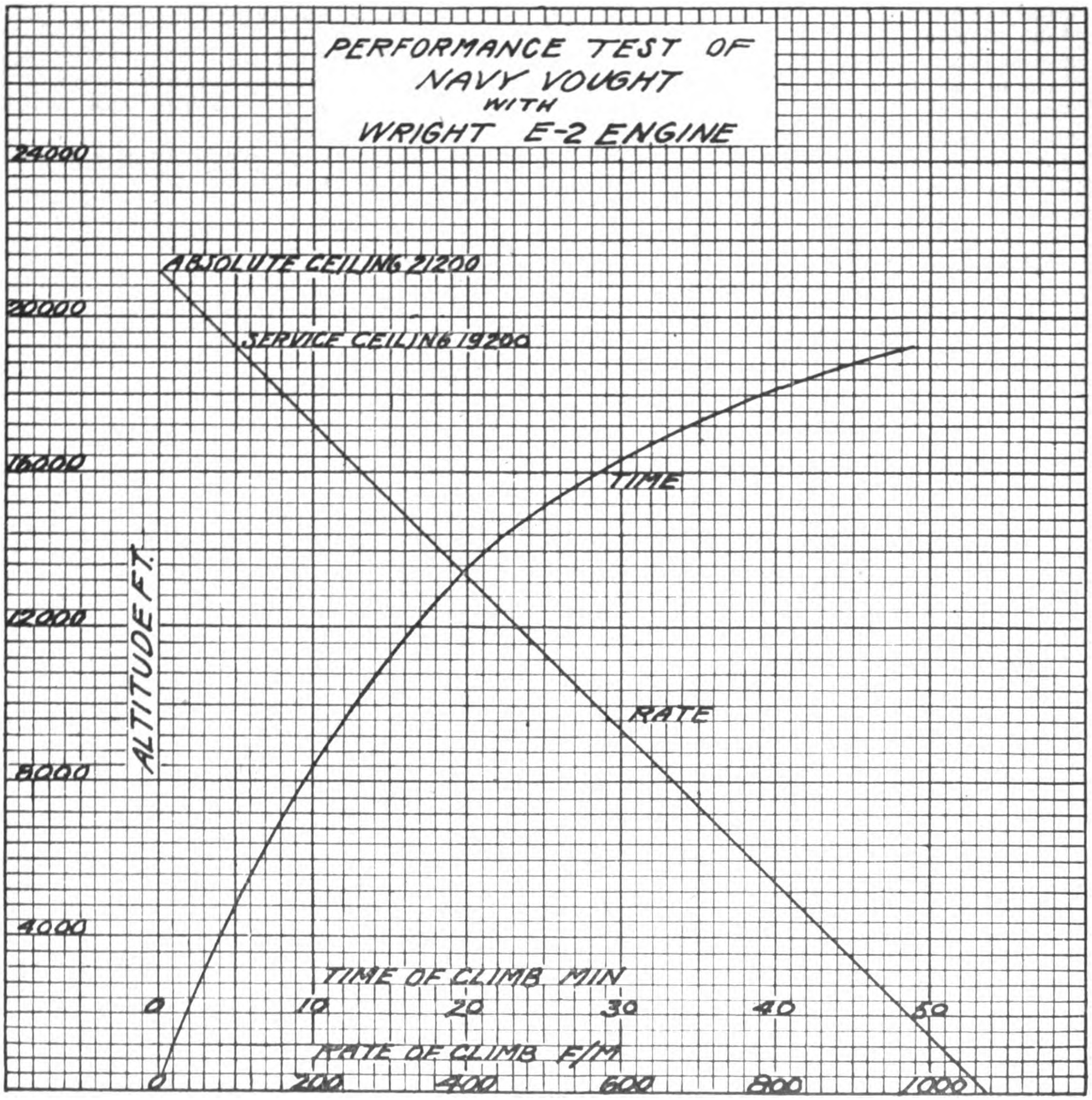

PERFORMANCE TEST OF
NAVY VOUGHT
WITH
WRIGHT E-2 ENGINE
24000
ABSOLUTE CEILING 21200
20000
SERVICE CEILING 19200
16000
TIME
ALTITUDE FT.
12000
RATE
8000
4000
TIME OF CLIMB MIN
0
10
20
30
40
50
RATE OF CLIMB F/M
0
200
400
600
800
1000

FIG. 1.

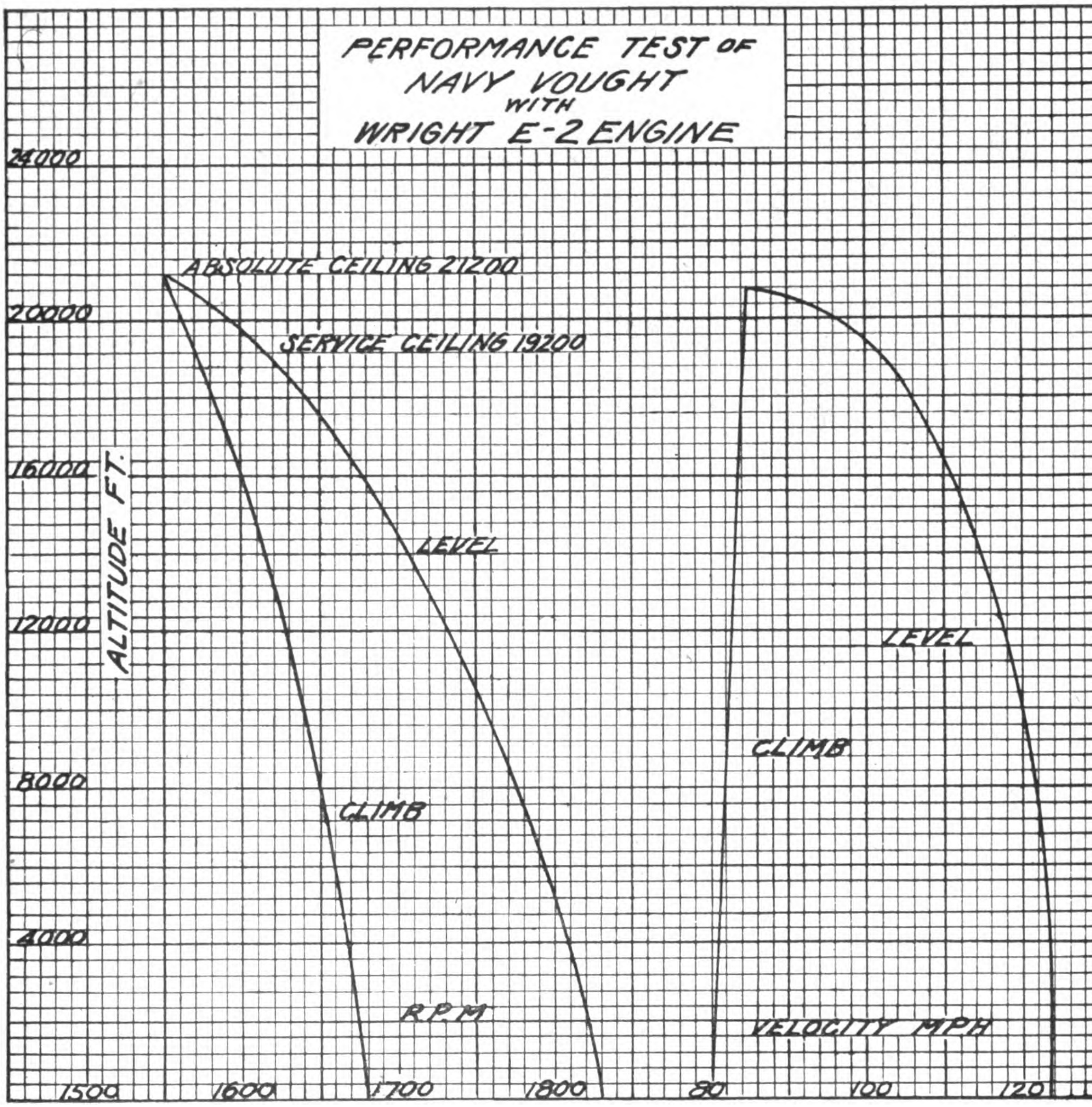

PERFORMANCE TEST OF
NAVY VOUGHT
WITH
WRIGHT E-2 ENGINE
24000
20000
16000
12000
8000
4000
ALTITUDE FT.
ABSOLUTE CEILING 21200
SERVICE CEILING 19200
LEVEL
CLIMB
R.P.M
LEVEL
CLIMB
VELOCITY MPH
1500
1600
1700
1800
80
100
120

Fig. 2.

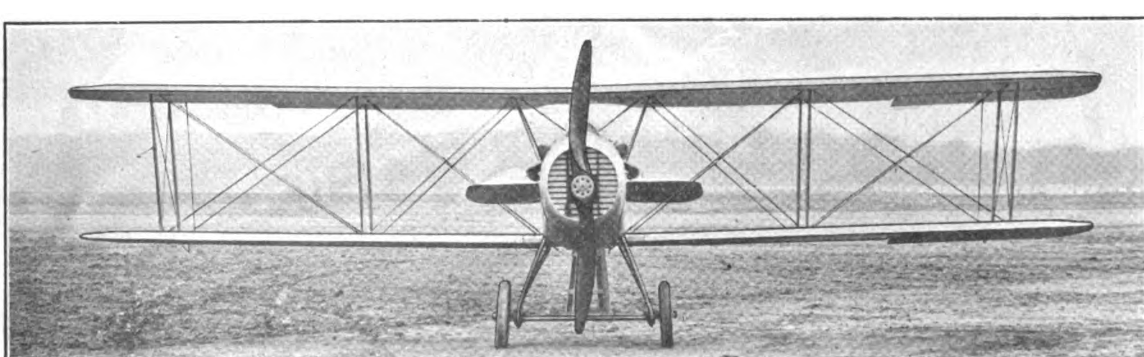


Fig. 3.

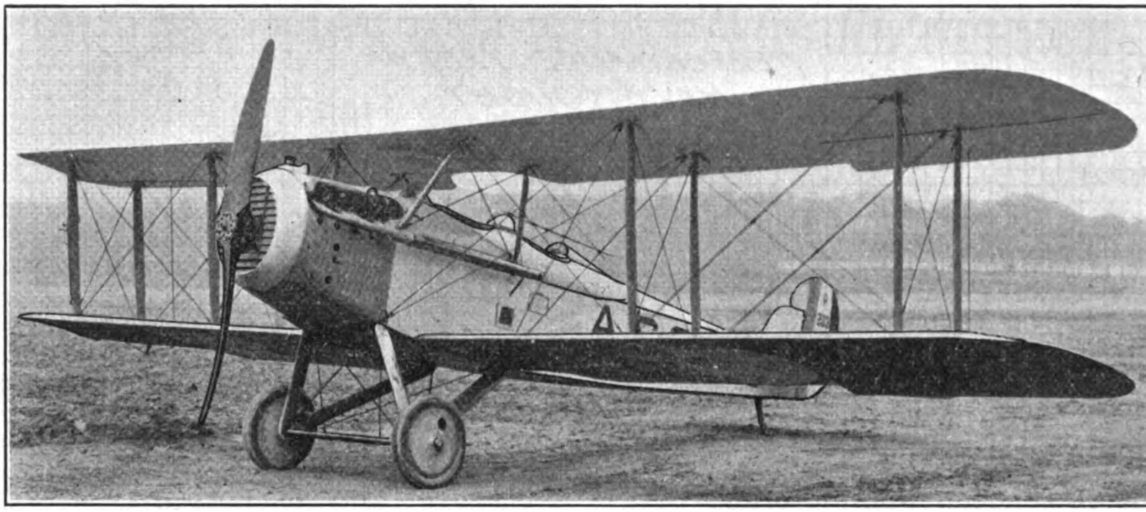


FIG. 4.

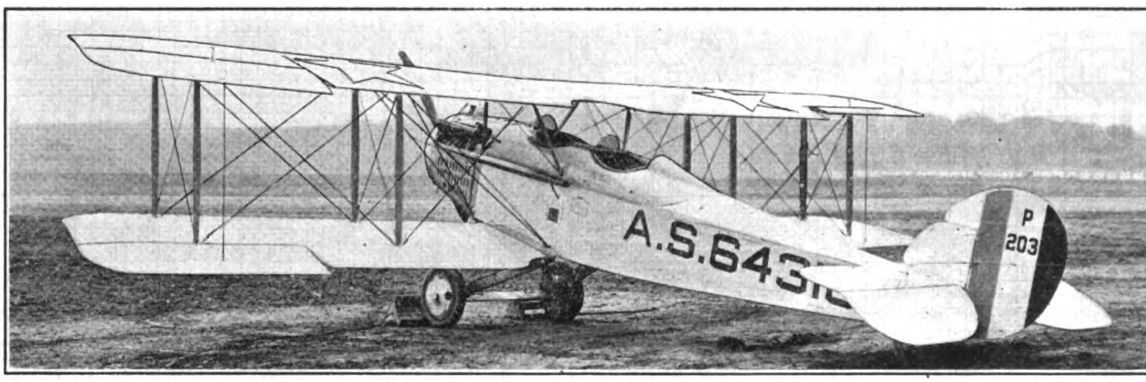


FIG. 5.

FIG. 6.

File D 52.333/67 *McCOOK FIELD REPORT, SERIAL No. 1876*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV June 1, 1922 No. 353

RESERVE BENDING STRENGTH OF STRUTS

(AIRPLANE SECTION, S. & A. BRANCH)

Prepared by R. A. Miller
Engineering Division, Air Service, McCook Field
Dayton, Ohio, March 3, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

RESERVE BENDING STRENGTH OF STRUTS.

The object of this investigation is to determine the comparative strength in bending of columns of various materials.

The struts are designed of square spruce, of Specification 10225 round steel tubes, of Specification 10227 round steel tubes and of round duralumin tubes, as columns with various lengths and axial loads.

The resulting columns are then investigated in bending, considering the column to be a simple beam, the maximum allowable concentrated load at the center computed and the results compared.

The columns are then investigated with combined axial and bending loads, each column being assumed to have an axial load equal to 80 per cent of the maximum allowable load, the allowable concentrated bending load at the center computed and the results compared.

CONCLUSIONS.

Spruce and duralumin tube columns designed for the same lengths and axial loads have about the same strength in bending. However, when considered with reference to the weights of the resulting columns, the spruce columns are slightly stronger than the duralumin columns for all lengths and loads covered by this investigation with the exception of the columns designed for the smaller axial loads.

Duralumin tube columns are much stronger in bending than Specification 10227 steel tube columns designed for the same lengths and axial loads. Comparison with reference to their respective weights is even more favorable to the duralumin tube columns.

Columns of Specification 10227 steel tubes weigh a little less, in general, than columns of Specification 10225 steel tubes designed for the same lengths and axial loads. However, the Specification 10227 steel tube columns are much stronger in bending than the Specification 10225 steel tube columns, and the difference is accentuated when the comparison is made with reference to their respective weights.

When compared with reference to their respective strengths with combined axial and bending loads, the square spruce columns in general have a slightly better strength-weight ratio than the duralumin tube columns; the duralumin tube columns have a much better strength-weight ratio than the Specification 10227 steel tube columns; and the Specification 10227 steel tube columns have a much better strength-weight ratio than the Specification 10225 steel tube columns.

Curves were developed, see Figure 1, to show the efficiency of the columns in bending when the bending stresses are combined with axial loads. The spruce columns are slightly more efficient in the Euler range than the columns of other materials, and the Specification 10225 round steel tube columns are the most efficient in the Johnson range. The efficiency of the columns in bending is low excepting for columns with low values of L/ρ, and for the range of this investigation, the efficiencies decrease rapidly as L/ρ approaches the dividing line between the Johnson and Euler ranges.

ASSUMPTIONS.

All columns are assumed to be pin-ended.

The following strength properties are assumed:

Material.	Compressive strength (pounds per square inch).	Modulus of rupture (pounds per square inch).	Modulus of elasticity (pounds per square inch).
Spruce	5,500	10,300	1,600,000
Specification 10227 steel	90,000	110,000	30,000,000
Specification 10225 steel	36,000	55,000	28,000,000
Duralumin	35,000	55,000	10,000,000

The following weights are assumed:

Spruce........................ 27 pounds per cubic foot
Duralumin.................... 175 pounds per cubic foot
Specification 10227 steel...... 490 pounds per cubic foot
Specification 10225 steel...... 485 pounds per cubic foot

COMPUTATIONS

Columns of each material are designed with lengths of 10 inches, 30 inches, 60 inches, and 100 inches.

or each length of the various materials columns are designed for axial loads of 1,000 pounds, 5,000 pounds, 10,000 pounds, and 20,000 pounds.

When the allowable load per square inch is greater than 50 per cent of the ultimate compressive strength of the material, Johnson's column formula is used:

$$\frac{P}{A}=f-\frac{f^2}{4C\pi^2E}\times\frac{(L)^2}{(\rho)^2}$$

When the allowable load per square inch is less than 50 per cent of the ultimate compressive strength, Euler's column formula is used:

$$P=\frac{C\pi^2EI}{L^2}$$

As the columns are assumed to be pin-ended, the constant "C" is equal to 1.0 in each case.

In designing the square spruce columns theoretical sizes are used.

In designing the steel and duralumin tube columns the nearest stock size is used, and the concentrated load in bending is corrected for the difference between the stock size and the theoretical size of the column.

Considering the designed columns to be simple beams, the maximum concentrated load at the center is computed by the following formula:

$$\text{The maximum moment}=\frac{PL}{4}=M=\frac{fI}{y}$$

$$P=\frac{4fI}{Ly}$$

where P is the allowable concentrated load at the center.

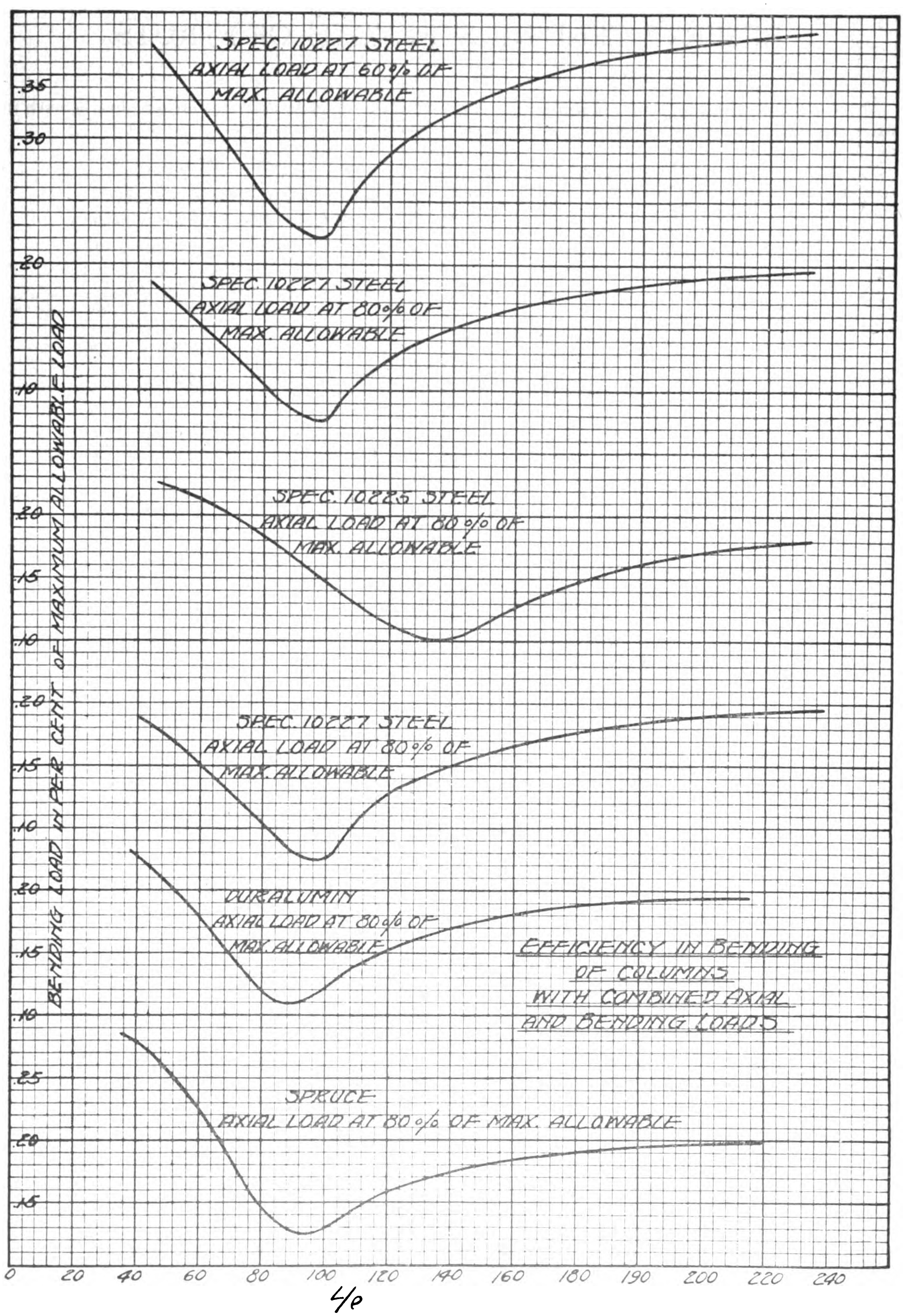

SPEC. 10227 STEEL
AXIAL LOAD AT 60% OF
MAX. ALLOWABLE
SPEC. 10227 STEEL
AXIAL LOAD AT 80% OF
MAX. ALLOWABLE
SPEC. 10225 STEEL
AXIAL LOAD AT 80% OF
MAX. ALLOWABLE
SPEC. 10227 STEEL
AXIAL LOAD AT 80% OF
MAX. ALLOWABLE
DURALUMIN
AXIAL LOAD AT 80% OF
MAX. ALLOWABLE
EFFICIENCY IN BENDING
OF COLUMNS
WITH COMBINED AXIAL
AND BENDING LOADS
SPRUCE
AXIAL LOAD AT 80% OF MAX. ALLOWABLE
BENDING LOAD IN PER CENT OF MAXIMUM ALLOWABLE LOAD
L/ρ

Fig. 1.

The properties of the designed columns for various materials, lengths, and axial loads are shown in Tables 1, 2, 3, and 4.

The maximum concentrated bending loads for the various columns considered as simple beams are shown in Table 5.

In investigating the columns for a combined axial load and concentrated bending load at the center, the following method is used:

F_c and F_b being assumed, f_c is computed for the column under consideration with an axial load equal to 80 per cent of the maximum allowable load. Substituting in the following formula, the value of f_b is obtained:

$$f_b+f_c=\frac{f_b}{f_b+f_c}\times(F_b-F_c)+F_c$$

$$f_b=\frac{F_b}{2}-f_c+\frac{1}{2}\sqrt{4F_cf_c-4F_bf_c+F_b^2}$$

The maximum moment for a simple beam with a concentrated load at the center $=M=PL/4$.

$$M=M'\times\left(1-\frac{P_1L^2}{10\,EI}\right)=\frac{PL}{4}$$

$$M'=\frac{f_b\,I}{y}$$

$$P=\frac{4f_bI}{Ly}\times\left(1-\frac{P_1L^2}{10\,EI}\right)$$

where P=concentrated bending load at the center

P_1=axial load.

The resulting allowable concentrated bending loads computed in combined compression and bending are to be found in Table 6.

Curves showing the efficiency of the resultant columns in combined compression and bending are shown in Figure 1. The ratio of the allowable bending load in combined compression and bending to the maximum allowable bending load is plotted as ordinates, and the values of L/ρ are plotted as abscissæ.

TABLE 1.—*Square spruce columns.*

Length.	Direct compression.	Width.	Area.	I.	L/ρ	Allowable F_c.	Maximum axial load.	P_b.	P'_b.	Weight.
10	1,000	0.536	0.287	0.0069	64.6	3,500	1,000	105	14.3	0.045
10	5,000	1.008	1.016	.0860	34.4	4,935	5,000	703	171.2	.159
10	10,000	1.388	1.926	.3093	24.9	5,210	10,000	1,840	498.0	.301
10	20,000	1.934	3.740	1.1660	17.9	5,350	20,000	4,960	1,401.0	.585
30	1,000	.909	.827	.0570	114.2	1,208	1,000	172	29.6	.388
30	5,000	1.360	1.850	.2851	76.5	2,715	5,000	575	72.8	.867
30	10,000	1.660	2.756	.6328	62.6	3,620	10,000	1,046	144.8	1.292
30	20,000	2.140	4.580	1.7477	48.5	4,370	20,000	2,250	432.0	2.147
60	1,000	1.286	1.654	.2279	161.3	605	1,000	243	46.5	1.550
60	5,000	1.923	3.698	1.1370	107.8	1,350	5,000	813	135.8	3.466
60	10,000	2.287	5.230	2.2800	90.8	1,905	10,000	1,370	204.5	4.905
60	20,000	2.720	7.398	4.5616	76.5	2,700	20,000	2,300	288.6	6.935
100	1,000	1.660	2.756	.6328	208.7	363	1,000	314	62.2	4.306
100	5,000	2.483	6.165	3.1676	139.4	810	5,000	1,052	193.0	9.633
100	10,000	2.952	8.714	6.3280	117.3	1,146	10,000	1,768	305.6	13.616
100	20,000	3.510	12.320	12.6487	98.8	1,628	20,000	2,950	470.0	19.250

P_b is the maximum allowable concentrated load in center of span considering the column as a simple beam.
P'_b is the allowable concentrated bending load at the center when the axial load on the column is equal to 80 per cent of the maximum allowable load.

TABLE 2.—*Duralumin tube columns.*

Length.	Direct compression.	Outside diameter.	Gauge.	Area.	I.	L/ρ	Allowable F_c.	Maximum axial load.	P_b.	P'_b.	Weight.
10	1,000	$\frac{1}{2}$	0.028	0.0415	0.00116	59.8	23,880	992	102	12.3	0.042
10	5,000	$\frac{7}{8}$	$\frac{1}{16}$	.1595	.0132	34.7	31,260	4,980	663	129.7	.162
10	10,000	$1\frac{1}{8}$	$\frac{3}{32}$	.3037	.0407	27.3	32,680	9,930	1,590	338.4	.307
10	20,000	$1\frac{3}{8}$	$\frac{5}{32}$	.5983	.1129	23.0	33,360	19,980	3,614	800.0	.606
30	1,000	$\frac{7}{8}$	.049	.1272	.0109	102.5	9,390	1,194	182	28.5	.386
30	5,000	$1\frac{1}{8}$	$\frac{1}{8}$	.3927	.04985	81.9	13,920	5,470	651	84.0	1.192
30	10,000	$1\frac{3}{8}$	$\frac{1}{8}$	.4909	.0968	67.5	20,850	10,220	1,032	110.4	1.490
30	20,000	$1\frac{3}{4}$	$\frac{5}{32}$	.7824	.2508	53.0	26,250	20,540	2,100	294.0	2.375
60	1,000	$1\frac{1}{4}$	$\frac{1}{16}$	.2332	.0412	142.7	4,840	1,128	242	44.1	1.417
60	5,000	$1\frac{1}{2}$	$\frac{7}{32}$	.8805	.1859	130.4	5,790	5,100	908	158.6	5.350
60	10,000	2	$\frac{5}{32}$	.9051	.3873	91.7	11,730	10,620	1,420	200.0	5.500
60	20,000	$2\frac{1}{4}$	$\frac{7}{32}$	1.396	.7283	83.2	14,320	20,000	2,374	307.4	8.475
100	1,000	$1\frac{1}{2}$	$\frac{3}{32}$	.4142	.1008	200.4	2,410	997	296	57.4	4.200
100	5,000	2	$\frac{7}{32}$	1.2242	.4928	157.4	3,970	4,865	1,083	201.6	12.390
100	10,000	$2\frac{1}{2}$	$\frac{7}{32}$	1.5678	1.0290	123.2	6,470	10,150	1,810	311.5	15.870
100	20,000	3	$\frac{1}{4}$	2.1599	2.0590	102.3	10,060	20,300	3,020	472.0	21.870

P_b is the maximum concentrated load in center of span considering the column as a simple beam.
P'_b is the allowable concentrated bending load at the center when the axial load on the column is equal to 80 per cent of the maximum allowable load.

TABLE 3.—*Steel tube columns, Spec. 10227.*

Length.	Direct compression.	Outside diameter.	Gauge.	Area.	*I.*	L/ρ.	Allowable F_c.	Maximum axial load.	P_b.	P'_b.	Weight.
10	1,000	11/32	0.028	0.0278	0.00035	89.2	37,200	1,034	89.5	9.5	0.079
10	5,000	3/4	.028	.0635	.00414	39.1	79,500	5,050	486.0	72.9	.180
10	10,000	1 1/8	.035	.1199	.0178	25.9	85,400	10,230	1,392.0	251.0	.340
10	20,000	1 1/4	1/16	.2332	.0412	23.8	86,120	20,080	2,900.0	532.5	.661
30	1,000	5/8	.035	.0649	.00283	143.4	14,310	930	133.0	22.5	.552
30	5,000	1	.049	.1464	.0166	89.1	37,260	5,460	487.0	50.9	1.245
30	10,000	1 1/8	1/16	.2086	.0295	79.7	47,500	9,920	769.0	57.3	1.775
30	20,000	1 1/8	3/16	.5522	.0631	88.7	37,500	20,740	1,644.0	170.6	4.700
60	1,000	7/8	1/16	.1595	.0132	208.2	6,560	1,085	221.0	42.1	2.714
60	5,000	1 1/8	3/16	.5522	.0631	177.4	9,400	5,190	822.0	149.4	9.400
60	10,000	1 3/8	3/16	.6995	.1264	141.1	14,870	10,400	1,348.0	222.4	11.900
60	20,000	1 3/4	5/32	.7824	.2508	106.0	26,340	20,600	2,100.0	280.5	13.300
100	1,000	1 1/4	.049	.1849	.0334	235.4	5,340	988	235.0	45.9	5.240
100	5,000	1 3/4	3/32	.4878	.1678	170.6	10,170	4,970	844.0	152.0	13.830
100	10,000	1 3/4	1/4	1.1781	.3405	186.0	8,560	10,080	1,712.0	317.0	33.400
100	20,000	2 1/4	7/32	1.3960	.7283	138.4	15,470	21,600	2,852.0	463.0	39.580

P_b is the maximum concentrated load in center of span considering the column as a simple beam.
P'_b is the allowable concentrated bending load at the center when the axial load on the column is equal to 80 per cent of the maximum allowable load.

TABLE 4.—*Steel tube columns, Spec. 10225.*

Length.	Direct compression.	Outside diameter.	Guage.	Area.	*I.*	L/ρ.	Allowable F_c.	Maximum axial load.	P_b.	P'_b.	Weight.
10	1,000	13/32	0.028	0.03325	0.000597	74.6	29,480	980	65	10.2	0.093
10	5,000	5/8	3/32	.1565	.0057	52.3	32,780	5,130	402	78.8	.439
10	10,000	7/8	1/8	.2945	.02128	37.2	34,380	10,120	1,070	231.5	.827
10	20,000	1 1/8	3/16	.5522	.0631	29.6	35,000	19,320	2,470	552.5	1.550
30	1,000	5/8	.049	.0887	.0037	146.7	12,800	1,137	87	11.6	.746
30	5,000	1	1/16	.1841	.0203	90.3	26,450	4,870	298	38.6	1.549
30	10,000	1 1/4	3/32	.3406	.0573	73.2	29,730	10,120	6"2	108.3	2.866
30	20,000	1 1/2	5/32	.6596	.1509	62.7	31,400	20,700	1,475	263.5	5.550
60	1,000	7/8	1/16	.1595	.0132	208.3	6,350	1,012	110	19.3	2.686
60	5,000	1 1/4	1/8	.4418	.07075	150.0	12,280	5,430	415	57.3	7.440
60	10,000	1 1/2	1/8	.5400	.1287	122.7	18,340	9,910	628	65.4	9.090
60	20,000	1 3/4	3/16	.9204	.2849	107.7	22,400	20,600	1,193	126.3	15.500
100	1,000	1 1/4	.049	.1849	.0334	235.0	4,980	923	117	21.2	5.185
100	5,000	1 1/2	7/32	.8805	.1859	217.0	5,830	5,130	546	96.2	24.700
100	10,000	2	5/32	.9051	.3873	152.7	11,820	10,700	852	120.0	25.400
100	20,000	2 1/4	7/32	1.396	.7283	138.3	14,410	20,140	1,425	179.0	39.170

P_b is the maximum concentrated load in center of span considering the column as a simple beam.
P'_b is the allowable concentrated bending load at the center when the axial load on the column is equal to 80 per cent of the maximum allowable load.

TABLE 5.—*Concentrated bending loads.*

Material.	Axial design load.	Length=10 inches.		Length=30 inches.		Length=60 inches.		Length=100 inches.	
		Weight.	P_b.	Weight.	P_b.	Weight.	P_b.	Weight.	P_b.
Square spruce	1,000	0.05	105	0.39	172	1.55	243	4.31	314
Duralumin tubes	1,000	.04	103	.32	152	1.26	214	4.21	297
Spec. 10227 steel tubes	1,000	.08	86.5	.59	143	2.60	203.5	5.30	237.5
Spec. 10225 steel tubes	1,000	.09	66	.66	77	2.66	109	5.62	127
Square spruce	5,000	.16	703	.87	575	3.47	813	9.63	1,052
Duralumin tubes	5,000	.16	665	1.09	595	5.24	891	12.63	1,113
Spec. 10227 steel tubes	5,000	.18	481	1.14	447	9.05	792	13.91	849
Spec. 10225 steel tubes	5,000	.43	392	1.59	306	6.85	382	24.07	532
Square spruce	10,000	.30	1,840	1.29	1,046	4.91	1,370	13.62	1,768
Duralumin tubes	10,000	.31	1,600	1.46	1,010	5.18	1,337	15.62	1,783
Spec. 10227 steel tubes	10,000	.33	1,360	1.79	776	11.43	1,296	33.14	1,698
Spec. 10225 steel tubes	10,000	.82	1,057	2.83	664	9.17	633	23.74	796
Square spruce	20,000	.59	4,960	2.15	2,250	6.94	2,300	19.25	2,950
Duralumin tubes	20,000	.61	3,616	2.31	2,046	8.48	2,374	21.55	2,974
Spec. 10227 steel tubes	20,000	.66	2,888	4.53	1,587	12.91	2,038	36.64	2,640
Spec. 10225 steel tubes	20,000	1.60	2,556	5.36	1,426	15.05	1,158	38.95	1,417

In designing the tube colums for the different lengths and loads the nearest stock size is used, the maximum allowable axial load computed for the size chosen, P_b computed for the size chosen and P_b is then corrected as follows:

Let A=axial load used in design of column.
B=maximum allowable axial load for the tube used.
y=maximum concentrated bending load at center.
x=corrected value of P_b.

$$x=\frac{Ay}{B}$$

The weights of the metal columns are corrected to the weight of the theoretical size in the same manner as the bending loads.

TABLE 6.—*Combined axial and concentrated bending loads.*

Material.	Axial design load.	Actual axial load.	Length=10 inches.		Length=30 inches.		Length=60 inches.		Length=100 inches.	
			Weight.	P'_b.	Weight.	P'_b.	Weight.	P'_b.	Weight.	P'_b.
Square spruce	1,000	800	0.05	14.3	0.39	29.6	1.55	46.5	4.31	62.2
Duralumin tubes	1,000	800	.04	12.4	.32	23.9	1.26	39.1	4.21	57.6
Spec. 10227 steel tubes	1,000	800	.08	9.2	.59	24.2	2.60	38.8	5.30	46.5
Spec. 10225 steel tubes	1,000	800	.09	10.4	.66	10.2	2.66	19.1	5.62	22.9
Square spruce	5,000	4,000	.16	171.2	.87	72.8	3.47	135.8	9.63	193.0
Duralumin tubes	5,000	4,000	.16	130.2	1.09	76.8	5.24	155.4	12.63	207.4
Spec. 10227 steel tubes	5,000	4,000	.18	72.2	1.14	46.7	9.05	143.9	13.91	153.0
Spec. 10225 steel tubes	5,000	4,000	.43	76.8	1.59	39.6	6.85	52.7	24.07	93.8
Square spruce	10,000	8,000	.30	498.0	1.29	144.8	4.91	204.5	13.62	305.6
Duralumin tubes	10,000	8,000	.31	340.5	1.46	108.1	5.18	188.5	15.62	307.2
Spec. 10227 steel tubes	10,000	8,000	.33	245.3	1.79	57.7	11.43	213.8	33.14	314.5
Spec. 10225 steel tubes	10,000	8,000	.82	229.0	2.83	107.1	9.17	66.0	23.74	112.2
Square spruce	20,000	16,000	.59	1,401.0	2.15	432.0	6.94	288.6	19.25	470.0
Duralumin tubes	20,000	16,000	.61	801.0	2.31	286.2	8.48	307.4	21.55	465.0
Spec. 10227 steel tubes	20,000	16,000	.66	530.0	4.53	164.5	12.91	272.3	36.64	428.5
Spec. 10225 steel tubes	20,000	16,000	1.60	572.0	5.36	254.5	15.05	122.7	38.95	167.2

P'_b is the maximum allowable concentrated bending load at the center of the column when the column is sustaining an axial load equal to 80 per cent of the maximum allowable load. As the nearest stock size was used in the design of the tube columns, the values of P'_b have been corrected by proportion to the design axial load, as shown in note to Table 5.

The weights of the metal columns are corrected to the weight of the theoretical size by the same method as the bending loads.

O

File D 52.41 / Hispano-Suiza / 106

McCOOK FIELD REPORT, SERIAL No. 1854

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | July 15, 1922 | No. 354

VARIATION IN PERFORMANCE OF A HISPANO-SUIZA (MODEL E) ENGINE WITH DEGREE OF THROTTLE OPENING

(POWER PLANT SECTION REPORT)

▽

Prepared by
H. G. Morse, A. M. E., Test Engineer
Engineering Division, Air Service
McCook Field, Dayton, Ohio
February 15, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

VARIATION IN PERFORMANCE OF A HISPANO-SUIZA (MODEL E) ENGINE WITH DEGREE OF THROTTLE OPENING.

OBJECT OF TEST.

The object of this test was to determine the variation in performance of a Hispano-Suiza (model E) engine with degree of throttle opening at various engine speeds.

CONCLUSIONS.

The power output obtained at given throttle openings over the entire speed range of the engine is shown by the curves in figure 1. The specific fuel consumptions are shown by the curves in figure 2. Actual test data are given in Table 1. The performance data corrected to even speeds are given in Table 2.

These data and the curves show the variation in performance of a Hispano-Suiza (model E) engine with degree of throttle opening at various engine speeds.

INTRODUCTION.

The Airplane Section of the Engineering Division, in order to make certain estimates of engine performance, wanted to determine the power output obtained on a typical airplane engine at given throttle openings over the entire speed range.

Two sets of runs were made on a Liberty "12" engine. It was found that at small throttle openings at any given speed, with the throttle securely locked in position, the manifold vacuum and the power fluctuated over a considerable range. The data for the tests on the Liberty engine are not included in this report as some variable, perhaps snow in the intake header, prevented a reliable determination of the engine's performance.

Reliable data were obtained on the Hispano-Suiza engine by using an intake air heater to maintain the temperature of the air supplied to the carburetor at approximately 95° F. It was possible to reproduce given conditions and check the performance within the limits of experimental error.

METHOD OF TEST.

Figures 3 and 4 show the installation of the Hispano-Suiza (model E) engine on the Sprague electric dynamometer. The method of connecting the carburetor to the intake air heater is clearly shown in the illustrations. The temperature of the air supplied to the carburetor was held at approximately 95° F. by controlling the amount of current supplied to the resistance coils of the air-heating element.

The following runs were made: [1]

(1) At full throttle, one power run from 800 revolutions per minute to 2,000 revolutions per minute, inclusive, in increments of 200 revolutions per minute.

(2) At the normal speed of 1,800 revolutions per minute, the throttle was gradually closed until 90 per cent of the full power was obtained. At this point the throttle was locked with a clamp and a set of power readings were obtained at the same speeds as indicated above.

(3) The general procedure outlined in paragraph (2) was repeated for throttle openings to give 80, 70, 60, 50, 40, 30, 20, and 10 per cent of the full power at the normal speed of 1,800 revolutions per minute. As the throttle was closed the speed at which the readings were started was lowered to 600 revolutions per minute.

(4) A friction run was made at each of the throttle openings and over the same speed range.

For method of taking readings and making the simpler standard computations, see Engineering Division Report Serial No. 1507.

The data tabulated in Table 2 was obtained in the following manner. The brake horsepower and the brake specific fuel consumption were obtained by reading the values directly from the curves at the intercepts of the even-speed ordinates. These curves are to be found in figures 1 and 2. The friction horsepower values were obtained in the same manner from curves plotted in pencil but not included in this report. The indicated horsepower was obtained by adding the brake and friction horsepowers. The mechanical efficiency was obtained by dividing the indicated into the brake horsepower. All the mean effective pressures were obtained by computation from the corresponding horsepowers. The indicated specific fuel consumption was obtained by multiplying the brake specific fuel consumption by the mechanical efficiency.

ANALYSIS.

The temperature of the air supplied to the carburetor was readily maintained at 95° F. At any engine speed for any given throttle opening the manifold vacuum and the power output checked with readings taken previously under the same conditions of speed and throttle opening.

It was observed that the operation of the engine with the mixture control set for best power was not as smooth as with a richer mixture and a slightly lower power.

All of the curves of brake horsepower output at partial throttle, figure 1, appear to merge into the full power curve at the lower engine speeds. That is, at 600 revolutions per minute approximately the same power is obtained at practically any throttle opening. The peak of each curve is reached at a lower speed with each decrease in throttle opening.

The specific fuel consumption curves, figure 2, show an increase in fuel consumption at the normal speed as the throttle is closed. There appears to be very little difference in specific fuel consumption at the lower engine speeds at the various throttle openings.

The friction horsepower (which includes the pumping losses) increases slightly for a given engine speed at the smaller throttle openings. This is particularly noticeable at the lower engine speeds. See Table 2.

[1] During each run and at each speed the mixture control was adjusted for maximum fuel economy consistent with maximum power and smooth operation.

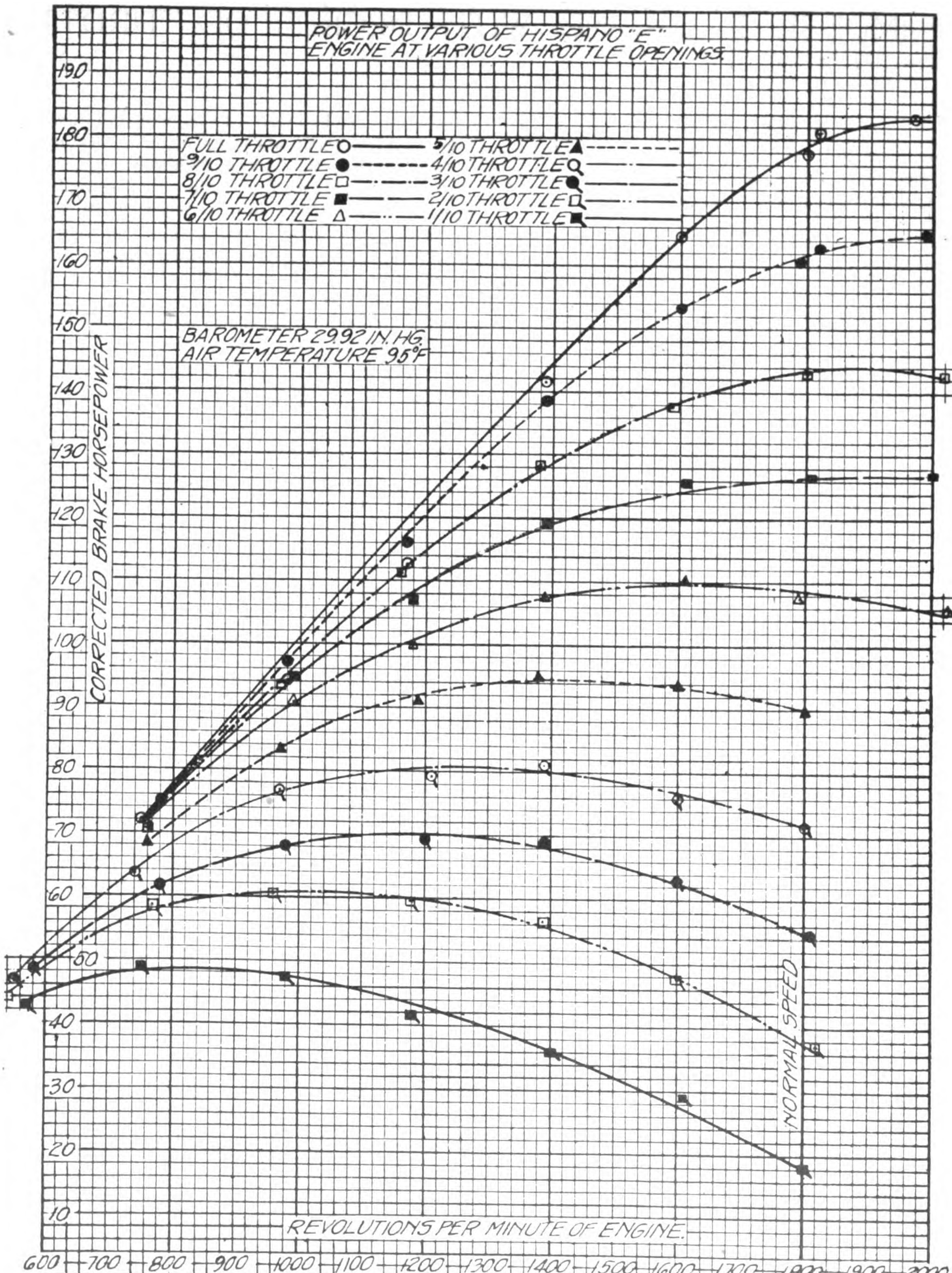

POWER OUTPUT OF HISPANO "E"
ENGINE AT VARIOUS THROTTLE OPENINGS.
FULL THROTTLE
9/10 THROTTLE
8/10 THROTTLE
7/10 THROTTLE
6/10 THROTTLE
5/10 THROTTLE
4/10 THROTTLE
3/10 THROTTLE
2/10 THROTTLE
1/10 THROTTLE
BAROMETER 29.92 IN. HG.
AIR TEMPERATURE 95°F
CORRECTED BRAKE HORSEPOWER
NORMAL SPEED
REVOLUTIONS PER MINUTE OF ENGINE.
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIG. 1.

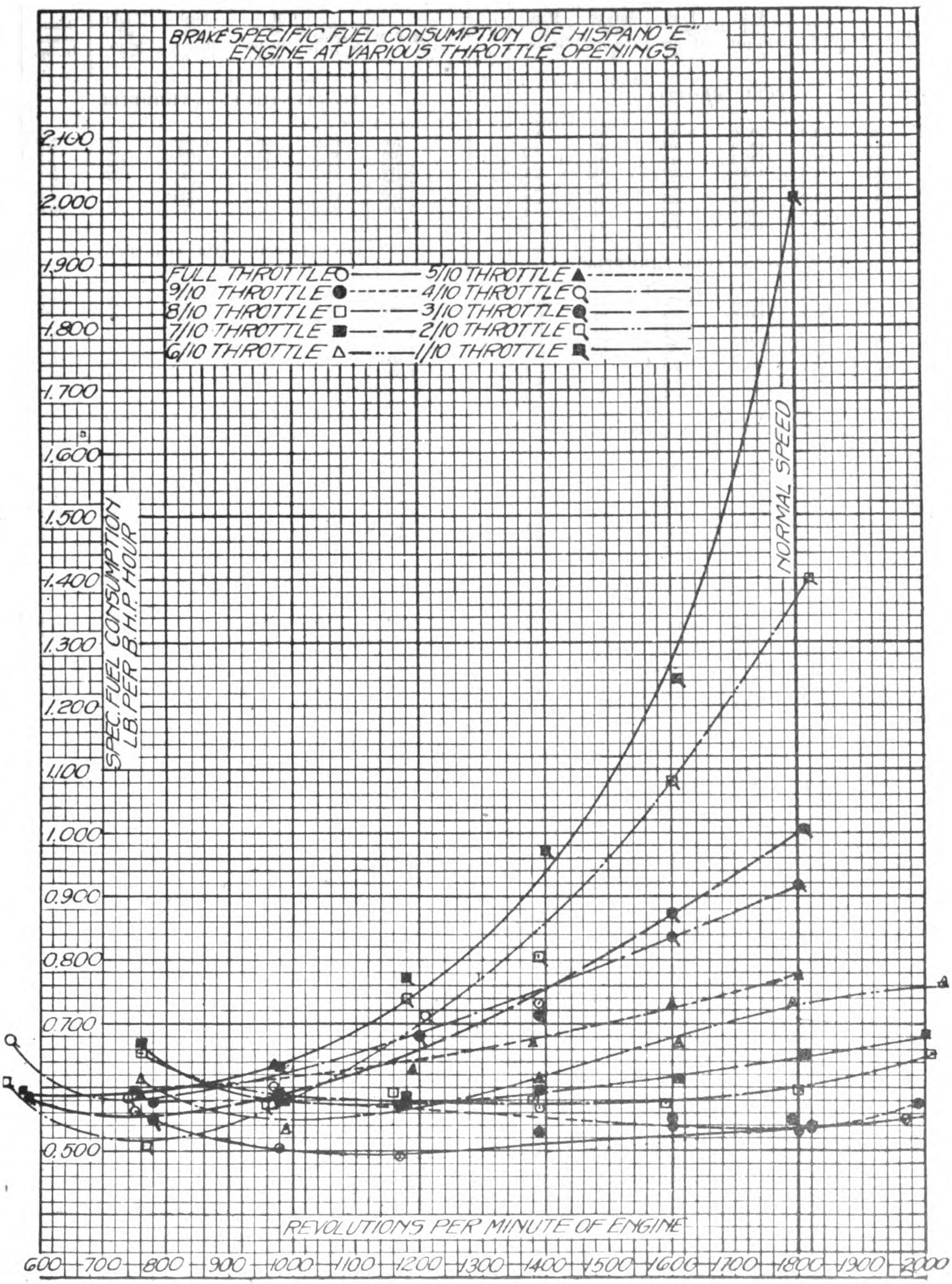

BRAKE SPECIFIC FUEL CONSUMPTION OF HISPANO "E" ENGINE AT VARIOUS THROTTLE OPENINGS.
FULL THROTTLE
9/10 THROTTLE
8/10 THROTTLE
7/10 THROTTLE
6/10 THROTTLE
5/10 THROTTLE
4/10 THROTTLE
3/10 THROTTLE
2/10 THROTTLE
1/10 THROTTLE
NORMAL SPEED
SPEC. FUEL CONSUMPTION LB. PER B.H.P. HOUR
REVOLUTIONS PER MINUTE OF ENGINE
2.100
2.000
1.900
1.800
1.700
1.600
1.500
1.400
1.300
1.200
1.100
1.000
0.900
0.800
0.700
0.500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

Fig. 2.

TABLE 1.—*Actual test data.*

R. P. M.	Corrected B. H. P.	B. M. E. P. lb. per sq. in.	Fuel cons. lb. per hp. hr.	Intake air temp. °F.	Man. vac. in. hg.
FULL THROTTLE.					
750	72.0	106.0	0.562	95	0.3
980	94.1	106.0	.503	95	.5
1,170	122.7	106.3	.489	94	.7
1,390	141.6	112.3	.567	95	1.1
1,600	164.6	113.5	.538	95	1.5
1,800	177.7	108.9	.529	94	1.7
1,820	181.0	109.8	.536	94	1.7
1,970	183.5	102.8	.550	95	1.9
NINE-TENTHS FULL THROTTLE.					
780	75.2	106.3	0.577	94	0.8
980	96.7	109.0	.579	95	1.5
1,170	115.9	109.3	.571	95	1.9
1,390	138.3	109.7	.527	95	2.6
1,600	153.3	105.4	.549	95	3.1
1,820	162.7	98.8	.539	94	3.5
1,790	160.6	99.1	.550	95	3.6
1,990	165.0	91.6	.574	96	4.0
EIGHT-TENTHS FULL THROTTLE.					
760	70.6	102.6	0.654	95	1.5
970	93.8	106.7	.574	95	2.3
1,160	111.3	105.8	.592	95	3.1
1,380	128.2	102.6	.580	95	3.9
1,590	137.8	95.7	.574	95	4.8
1,800	143.0	87.7	.596	95	5.6
2,010	142.4	78.2	.654	94	6.3
SEVEN-TENTHS FULL THROTTLE.					
760	70.6	102.6	0.667	97	1.9
990	94.4	105.2	.579	96	2.9
1,180	107.2	100.3	.586	94	3.8
1,390	119.2	94.7	.596	95	4.8
1,610	125.8	86.2	.615	95	5.7
1,810	126.4	77.1	.652	95	6.7
2,000	127.1	70.2	.682	86	7.4
SIX-TENTHS FULL THROTTLE.					
760	71.1	103.3	0.614	96	2.6
990	90.6	101.1	.535	95	3.8
1,180	99.9	93.5	.578	95	5.0
1,390	107.7	85.6	.613	95	6.2
1,610	110.3	75.6	.667	95	7.2
1,790	107.6	66.4	.733	94	8.2
2,030	105.8	57.7	.764	94	9.3

TABLE 1.—*Actual test data*—Continued.

R. P. M.	Corrected B. H. P.	B. M. E. P. lb. per sq. in.	Fuel cons. lb. per hp. hr.	Intake air temp. °F.	Man. vac. in. hg.
FIVE-TENTHS FULL THROTTLE.					
760	68.2	99.1	0.582	95	3.3
970	83.3	94.9	.636	95	4.9
1,190	91.1	84.5	.625	95	6.3
1,380	94.7	75.8	.670	95	7.5
1,600	93.7	64.7	.730	94	9.0
1,800	89.8	55.1	.777	95	10.0
FOUR-TENTHS FULL THROTTLE.					
550	46.7	93.8	0.673	95	2.7
740	63.6	94.9	.585	95	4.2
970	76.6	87.2	.599	95	6.1
1,210	79.2	72.4	.712	94	8.1
1,390	80.9	64.3	.730	95	9.4
1,600	76.0	52.4	.838	95	10.7
1,800	71.7	44.0	.915	94	11.7
THREE-TENTHS FULL THROTTLE.					
580	48.3	91.9	0.582	95	3.6
780	61.7	87.3	.547	95	5.5
980	68.0	76.6	.593	95	7.5
1,200	69.1	63.6	.680	94	9.4
1,390	69.0	54.7	.711	95	10.9
1,600	62.7	43.3	.875	96	12.3
1,810	54.6	33.3	1.019	95	13.4
TWO-TENTHS FULL THROTTLE.					
540	44.0	90.0	0.610	95	4.0
770	58.5	83.9	.508	95	6.6
960	60.3	69.3	.573	96	8.6
1,180	59.7	55.9	.740	97	10.9
1,390	56.4	44.8	.806	94	12.5
1,600	47.8	33.0	1.082	95	13.8
1,820	37.3	22.6	1.401	96	14.9
ONE-TENTH FULL THROTTLE.					
570	42.8	82.7	0.599	95	6.0
750	48.6	71.6	.598	96	8.8
980	47.6	53.6	.632	95	11.6
1,180	41.7	39.0	.773	94	13.4
1,400	35.9	28.3	.974	95	14.9
1,610	29.0	19.9	1.242	95	16.0
1,800	18.1	11.1	2.005	95	16.7

TABLE 2.—*Performance data corrected to even speeds.*

R. P. M.	Horsepower.			Mech. Eff. %	Mean effective press. lb. per sq. in.			Specific fuel cons. lb. per hp. hr.	
	Brake.	Friction.	Indicated.		Brake.	Friction.	Indicated.	Brake.	Indicated.
FULL THROTTLE.									
800	78.0	5.1	83.1	93.9	107.6	7.0	114.6	0.540	0.507
1,000	101.0	8.0	109.0	92.7	111.5	8.8	120.3	.500	.464
1,200	123.3	10.8	134.1	92.1	113.3	9.9	123.2	.498	.458
1,400	144.5	14.9	159.4	90.7	113.8	11.8	125.6	.510	.463
1,600	164.4	19.2	183.6	89.6	113.4	13.2	126.6	.522	.467
1,800	179.0	24.0	203.0	88.2	109.7	14.7	124.4	.535	.472
2,000	183.2	30.7	213.9	85.6	101.0	16.9	117.9	.555	.475
NINE-TENTHS FULL THROTTLE.									
800	77.7	5.3	83.0	93.6	107.2	7.3	114.5	0.579	0.542
1,000	99.6	9.3	108.9	91.4	109.9	10.3	120.2	.580	.530
1,200	120.5	12.0	132.5	91.0	110.7	11.0	121.7	.564	.513
1,400	139.3	15.4	154.7	90.1	109.8	12.1	121.9	.550	.495
1,600	153.3	19.2	172.5	88.9	105.7	13.2	118.9	.539	.479
1,800	161.7	22.8	184.5	87.6	99.1	14.0	113.1	.558	.471
2,000	165.0	29.3	194.3	84.9	91.3	16.2	107.5	.580	.492

TABLE 2.—*Performance data corrected to even speeds*—Continued.

R. P. M.	Horsepower.			Mech. Eff. %	Mean effective press. lb. per sq. in.			Specific fuel cons. lb. per hp. hr.	
	Brake.	Friction.	Indicated.		Brake.	Friction.	Indicated.	Brake.	Indicated.
EIGHT-TENTHS FULL THROTTLE.									
800	77.0	6.4	83.4	92.3	106.2	8.8	115.0	0.632	0.583
1,000	97.0	9.0	106.0	91.5	107.0	9.9	116.9	.586	.536
1,200	114.9	11.6	126.5	90.9	105.7	10.7	116.4	.576	.524
1,400	128.7	15.4	144.1	89.3	101.3	12.1	113.4	.573	.511
1,600	138.5	19.2	157.7	87.9	95.5	13.2	108.7	.580	.509
1,800	143.3	24.0	167.3	85.7	87.8	14.7	102.5	.600	.514
2,000	142.8	30.7	173.5	82.3	78.8	16.9	95.7	.650	.535
SEVEN-TENTHS FULL THROTTLE.									
800	76.5	6.9	83.4	91.8	105.5	9.5	115.0	0.635	0.583
1,000	95.2	9.0	104.2	91.4	105.0	9.9	114.9	.579	.529
1,200	109.5	11.6	121.1	90.5	100.6	10.7	111.3	.577	.522
1,400	119.0	15.4	134.4	88.5	93.8	12.1	105.9	.590	.522
1,600	124.0	19.7	143.7	86.3	85.6	13.6	99.2	.615	.531
1,800	126.5	24.0	150.5	84.1	77.6	14.7	92.3	.644	.541
2,000	127.0	32.0	159.0	79.9	70.1	17.7	87.8	.680	.543
SIX-TENTHS FULL THROTTLE.									
800	75.6	6.9	82.5	91.7	104.3	9.5	113.8	0.590	0.541
1,000	91.0	9.0	100.0	91.0	100.4	9.9	110.3	.550	.501
1,200	101.3	12.0	113.3	89.4	93.2	11.0	104.2	.570	.510
1,400	107.7	16.3	124.0	86.8	84.8	12.9	97.7	.619	.537
1,600	109.7	20.3	130.0	84.3	75.7	14.0	89.7	.679	.572
1,800	108.7	24.6	133.3	81.5	66.6	15.1	81.7	.728	.593
2,000	105.4	32.7	138.1	76.4	58.2	18.0	76.2	.756	.577
FIVE-TENTHS FULL THROTTLE.									
800	71.8	6.9	78.7	91.2	99.1	9.5	108.6	0.600	0.547
1,000	85.0	9.3	94.3	90.1	93.8	10.3	104.1	.616	.555
1,200	92.2	12.4	104.6	88.1	84.8	11.4	96.2	.642	.565
1,400	94.6	16.8	111.4	84.9	74.5	13.2	87.7	.680	.577
1,600	93.5	20.8	114.3	81.9	64.5	14.3	78.8	.721	.589
1,800	90.0	25.2	115.2	78.1	55.1	15.5	70.6	.780	.609
FOUR-TENTHS FULL THROTTLE.									
600	52.0	4.4	56.4	92.2	95.7	8.1	103.8	0.620	0.572
800	68.2	7.2	75.4	90.4	93.8	9.9	103.7	.585	.529
1,000	77.3	9.7	87.0	88.8	85.3	10.7	96.0	.625	.555
1,200	80.6	12.8	93.4	86.3	74.1	11.8	85.9	.683	.588
1,400	80.0	17.3	97.3	82.2	63.1	13.6	76.7	.755	.620
1,600	76.9	21.3	98.2	78.3	53.0	14.7	67.7	.835	.654
1,800	71.6	25.8	97.4	73.5	43.9	15.8	59.7	.912	.671
THREE-TENTHS FULL THROTTLE.									
600	50.0	4.4	54.4	91.9	92.0	8.1	100.1	0.575	0.529
800	62.4	7.2	69.6	89.7	86.1	9.9	96.0	.558	.501
1,000	68.5	10.3	78.8	86.9	75.6	11.4	87.0	.590	.513
1,200	70.0	13.2	83.2	84.1	64.4	12.1	76.5	.660	.555
1,400	68.0	17.7	85.7	79.3	53.6	14.0	67.6	.752	.596
1,600	62.4	22.4	84.8	73.6	43.0	15.5	58.5	.870	.640
1,800	55.0	27.0	82.0	67.1	33.7	16.6	50.3	.999	.671
TWO-TENTHS FULL THROTTLE.									
600	48.6	5.0	53.6	90.7	89.4	9.2	98.6	0.560	0.508
800	58.5	7.7	66.2	88.4	80.8	10.7	91.5	.520	.460
1,000	60.8	10.7	71.5	85.0	67.1	11.8	78.9	.581	.494
1,200	59.8	13.6	73.4	81.5	55.0	12.5	67.5	.700	.571
1,400	55.3	18.2	73.5	75.3	43.6	14.3	57.9	.860	.647
1,600	48.0	22.9	70.9	67.7	33.1	15.8	48.9	1.080	.731
1,800	37.6	27.6	65.2	57.7	23.1	16.9	40.0	1.366	.788
ONE-TENTH FULL THROTTLE.									
600	44.5	5.0	49.5	89.9	81.9	9.2	91.1	0.590	0.531
800	48.5	8.5	57.0	85.1	66.9	11.8	78.7	.597	.508
1,000	47.0	11.3	58.3	80.6	51.9	12.5	64.4	.642	.517
1,200	42.9	14.8	57.7	74.4	39.4	13.6	53.0	.750	.558
1,400	36.2	18.7	54.9	65.9	28.5	14.7	43.2	.940	.619
1,600	27.9	23.5	51.4	54.3	19.2	16.2	35.4	1.265	.687
1,800	18.0	28.2	46.2	39.0	11.0	17.3	28.3	2.000	.780

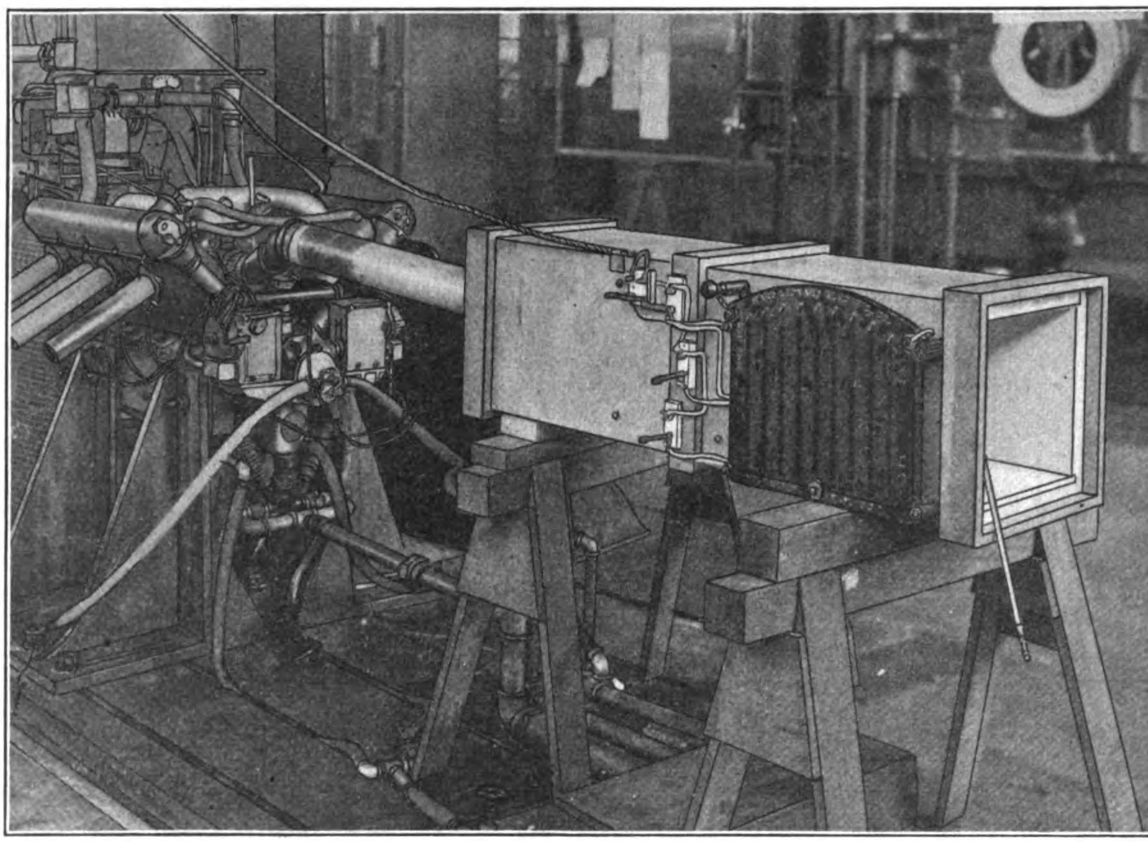


FIG. 3.—Installation on the dynamometer showing intake air heater connected to engine.

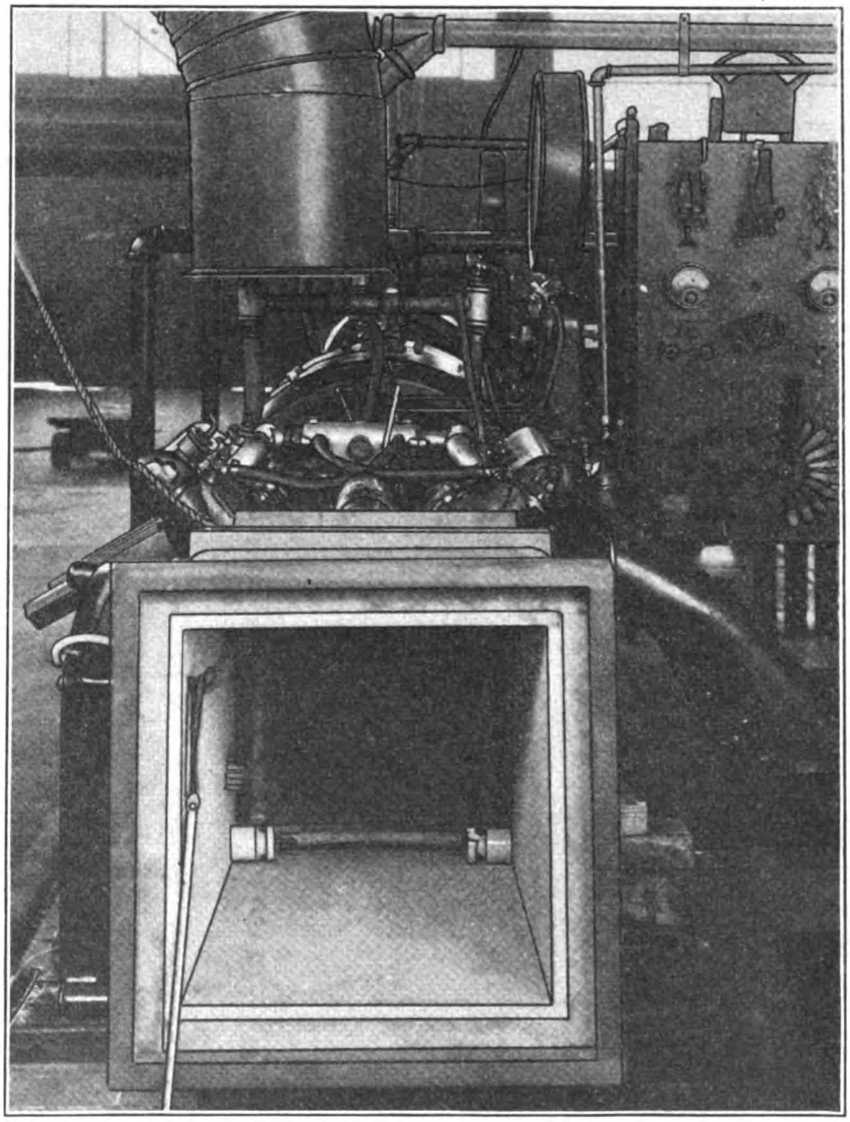


FIG. 4.—Installation on the dynamometer showing resistance coils.

File D 52.1 / DH 4 / 126

McCOOK FIELD REPORT, SERIAL No. 1868

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | June 15, 1922 | No. 355

REPORT OF WIND-TUNNEL TEST OF DH-4B MODEL

1. With 7½-inch positive stagger } Full scale
2. With 2-inch negative stagger }

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by Lieut. C. L. Morse, A. S.
Engineering Division, Air Service, McCook Field
Dayton, Ohio, October 7, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT OF WIND TUNNEL TEST OF DH-4B MODEL.

1. With $7\frac{1}{2}$-inch positive stagger
2. With 2-inch negative stagger

} Full scale.

A 1/24 scale model of the DH-4B airplane, with a 300 Wright engine, was constructed at McCook Field. It was tested at the Massachusetts Institute of Technology for lift drag, L/L and moments about the center of gravity for various angles of incidence and tail settings for both positive and negative stagger. Two tests were run, the first with $7\frac{1}{2}$-inch positive stagger (for the full scale airplane) and the second with 2-inch negative stagger (also for the full scale airplane).

OBJECT.

The object of the test, with positive stagger, was to obtain the correct tail setting for balance of this airplane, as it had been very tail heavy.

The object of the test, with negative stagger, was to obtain the proper balance of the airplane for additional weight due to machine guns.

RESULTS.

The forces are almost exactly equal for both positive and negative stagger, the most marked difference being in the minimum drag, which is about 40 per cent larger with negative stagger than with positive. The lift curves are everywhere alike within the experimental error, and the maximum L/D is absolutely identical in the two cases.

In examining the balance, the moments have been plotted with reference to the original center of gravity. The airplane then trims at $-0.1°$ with a tail setting of $-1°$. With the same tail setting and the normal positive stagger the trimming angle was $+8°$.

To secure perfect balance with the negative stagger and the same tail setting at the original trimming angle of $+8°$, the center of gravity would have to be moved back .26 inches on the model, the equivalent of 6.2 inches on the full sized airplane. This is more than half the change in stagger.

For the same degree of stability the center of gravity must be much farther forward on the mean chord for negative stagger than for positive.

DISCUSSION.

The model was supported on an end spindle in the upper wing. The runs for lift and drag were made at 30 miles per hour throughout, but when moments were taken the vibration was so great that the speed had to be reduced to 20 miles per hour at all angles beyond, but not including 14°.

The model had a positive stagger of $7\frac{1}{2}$ inches (full scale) and the wing section was the R. A. F. 15.

The tail plane was set at $-1°$ to the upper wing.

The lift curve shows the characteristic, so frequently observed in tests of complete models, of gradual increase to a maximum at a very high angle, $+25°$ in this case. The maximum L/D is good for a machine of this type, and the ratio of the maximum lift to minimum drag is 19.6. The maintenance, over a large range of a very high lift, is probably due in this case to biplane effect primarily, the lift of the lower wing increasing while that of the upper decreases up to an angle of about 40°.

The moment curve indicates satisfactory stability down as far as the angle of zero lift. The degree of stability increases, with increase of angle, becoming excessive at angles beyond $+14°$. This is quite at variance with the results of a free flight test on the DH-4, in which the stability was found to be greatest at high speeds, the machine becoming unstable with free controls in the neighborhood of the minimum speed.

A second test was run, using the same model except that it had 2-inch (full scale) negative stagger instead of $7\frac{1}{2}$-inch (full scale) positive stagger. The model was supported exactly as before.

As the primary object of this test was to investigate the effect of the negative stagger on balance, the maximum lift being little affected by stagger, the angle of attack was only carried up to 12°, thus averting the danger of injury to the model by its vibration at large angles.

In order to show more forcibly the effect on stability and balance of a change in stagger, the moment curves for the positive stagger with the original center of gravity and for the negative stagger with the center of gravity moved back six (6) inches (full scale) have been plotted. The airplane balances very nearly under the same conditions for these two cases, the moment curves intersecting at 8°, but the curves are entirely different in form. That for positive stagger has a large negative slope at all positive angles, while the curve for negative stagger is practically horizontal throughout. The effect of positive stagger, even when not accompanied by decalage, in increasing stability is this clearly shown.

For the same degree of stability, the center of gravity must be much farther forward on the mean chord for negative stagger than for positive. It follows, that to make the stability and balance both the same in the two cases, the angle of negative tail setting must be increased as the stagger decreases. The proper allowance for the effect of

stagger can be made automatically if, instead of taking the mean chord midway between the two wings, it be taken much nearer the lower wing. It might be mentioned that the same phenomenon has been noted in free flight testing. (Report No. 96, N. A. C. A.), where a decrease of stagger was found to produce much less favorable effect on stability than had been anticipated from the resultant shift of the center of gravity position on the mean chord.

The characteristics of the DH-4B with both positive and negative stagger are given in the following tables and the results are also plotted, in figures 1-5 inclusive.

Figure 6 is a three-view drawing of the DH-4B model.

TABLE 1.—*Positive Stagger 7½ inches (full scale) Tail Plane −1° to Wing Chord.*

Θ	L	D	L/D	$M_{c.g.}$
−4	−0.220	0.1174	−1.88	+0.29
−2	.052	.0987	+0.53	+ .12
0	.382	.0953	4.01	+ .05
+2	.731	.1064	6.86	+ .09
4	1.020	.1281	7.96	+ .10
6	1.311	.1581	8.30	− .04
8	1.572	.2000	7.86	+ .01
10	1.786	.2651	6.74	− .10
12	1.801	.4121	4.37	+ .03
14	1.833	.5295	3.46	− .70
16	1.874	.6428	2.92	−1.08
18	1.861	.7436	2.51	−1.35
20	1.863	.8333	2.24	−1.56
22	1.905	.9291	....	−1.85
24	....	....	....	....
28	....	....	....	....

Θ = angle chord of wing makes with wind.
L = lift in pounds.
D = drag in pounds.
$M_{c.g.}$ = moment about center of gravity in inch-pounds.
Velocity: 30 miles per hour.
Scale: 1/24.
MASSACHUSETTS INSTITUTE OF TECHNOLOGY, *August 9, 1921.*

TABLE 2.—*Positive Stagger 7½ inches (full scale) Tail Plane −1° to Upper Wing.*

Θ	L	D	L/D	$M_{c.g.}$
−4	....	0.114	....	+0.31
−2	+0.04	.100	+0.40	+ .53
0	.32	.096	3.34	+ .49
+2	.59	.104	5.67	+ .42
4	.815	.122	6.67	+ .32
6	1.055	.142	7.43	+ .21
8	1.32	.168	7.85	+ .07
10	1.56	.210	7.43	− .10
12	1.71	.266	6.42	− .22
14	1.75	.324	5.40	− .41
16	1.75	.370	4.73	− .97
18	1.76	.473	3.72	−1.46
20	1.79	.572	3.13	−1.76
22	1.84	.657	2.80	−2.0
24	1.87	.748	2.50	−2.23
26	1.87	.813	2.30	−2.44
28	1.86	.885	2.10	....

Velocity: 30 miles per hour.
MASSACHUSETTS INSTITUTE OF TECHNOLOGY, *August 27, 1921.*

TABLE 3.—*Negative Stagger 2 inches (full scale).*

Θ	L	D	L/D	Z	$M_{c.g.}$	X
−4	−0.39	0.131	−2.98	−0.31	+0.160	+0.110
−2	− .13	.111	−1.17	− .12	+ .117	.107
0	+ .15	.101	+1.485	+ .14	− .010	.101
+2	0.51	.102	5.00	.51	.146	.084
4	0.784	.116	6.76	.79	.225	.060
6	1.030	.136	7.57	1.04	.285	+ .024
8	1.260	.162	7.77	1.29	.330	− .016
10	1.480	.204	7.25	1.51	.382	− .058
12	1.690	.253	6.68	1.70	.485	− .102

Θ = angle chord makes with wind.
L = lift in pounds.
D = drag in pounds.
$M_{c.g.}$ = moment about center of gravity in inch pounds.
X = longitudinal force on model in pounds.
Z = normal force on model in pounds.
Velocity: 30 miles per hour.
MASSACHUSETTS INSTITUTE OF TECHNOLOGY, *September 6, 1921.*

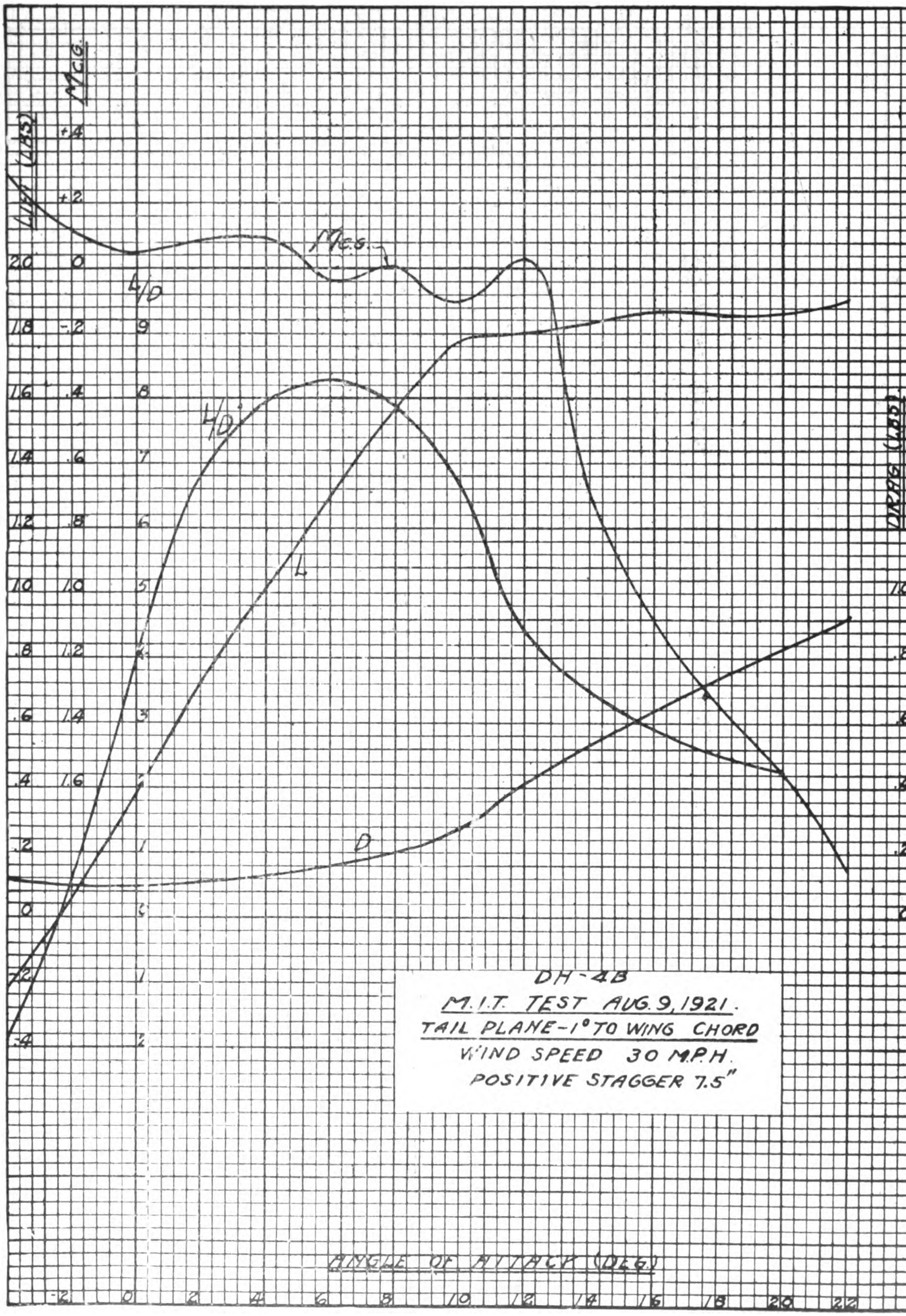

LIFT (LBS)
M_{CG}
M_{CG}
L/D
L/D
L
D
DRAG (LBS)
DH-4B
M.I.T. TEST AUG. 9, 1921.
TAIL PLANE -1° TO WING CHORD
WIND SPEED 30 M.P.H.
POSITIVE STAGGER 7.5"
ANGLE OF ATTACK (DEG.)

FIGURE 1.

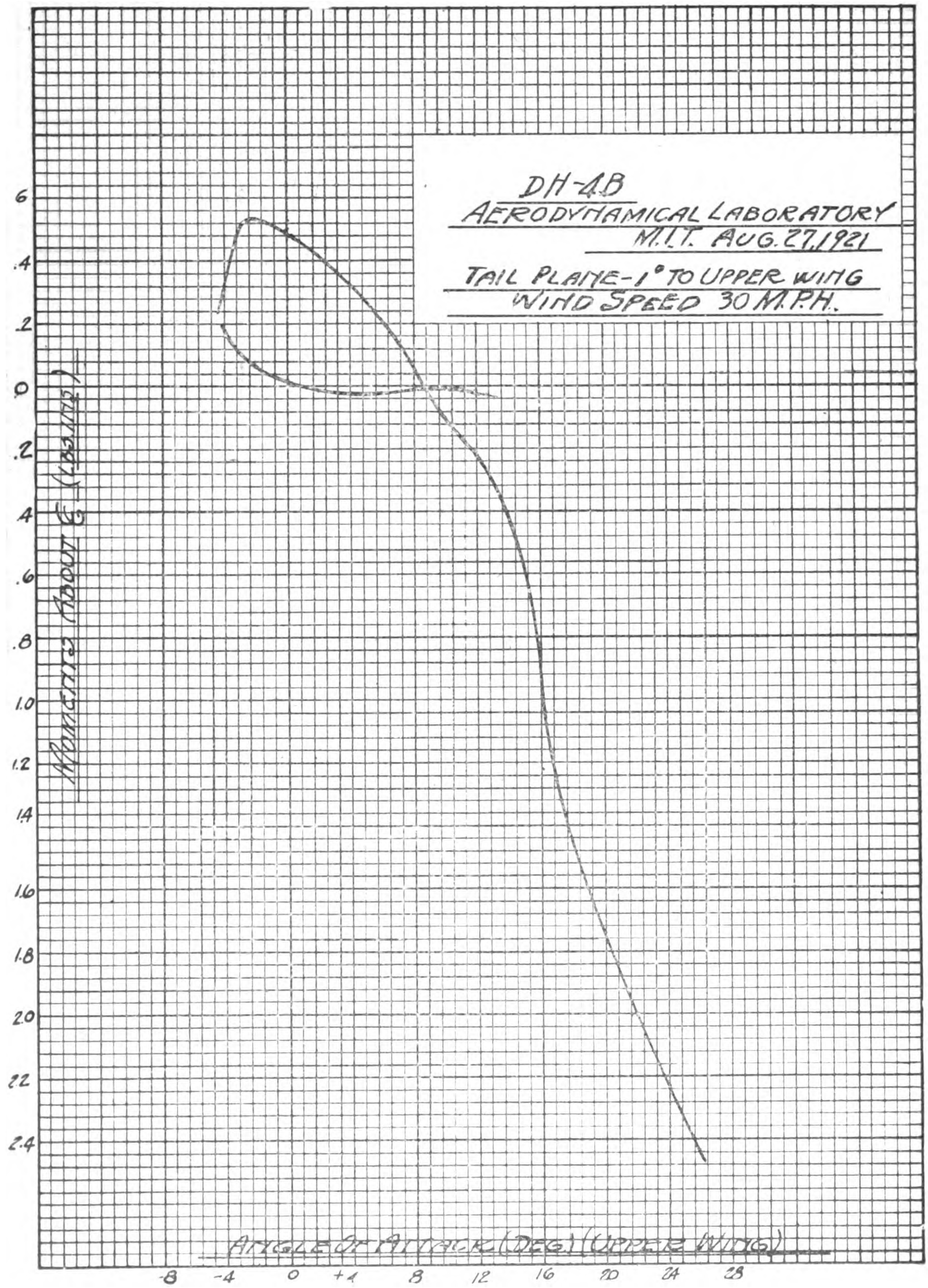

DH-4B
AERODYNAMICAL LABORATORY
M.I.T. AUG. 27, 1921
TAIL PLANE-1° TO UPPER WING
WIND SPEED 30 M.P.H.
MOMENTS ABOUT C.G. (LBS.INS)
ANGLE OF ATTACK (DEG) (UPPER WING)
.6
.4
.2
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
-8
-4
0
+4
8
12
16
20
24
28

FIG. 2.

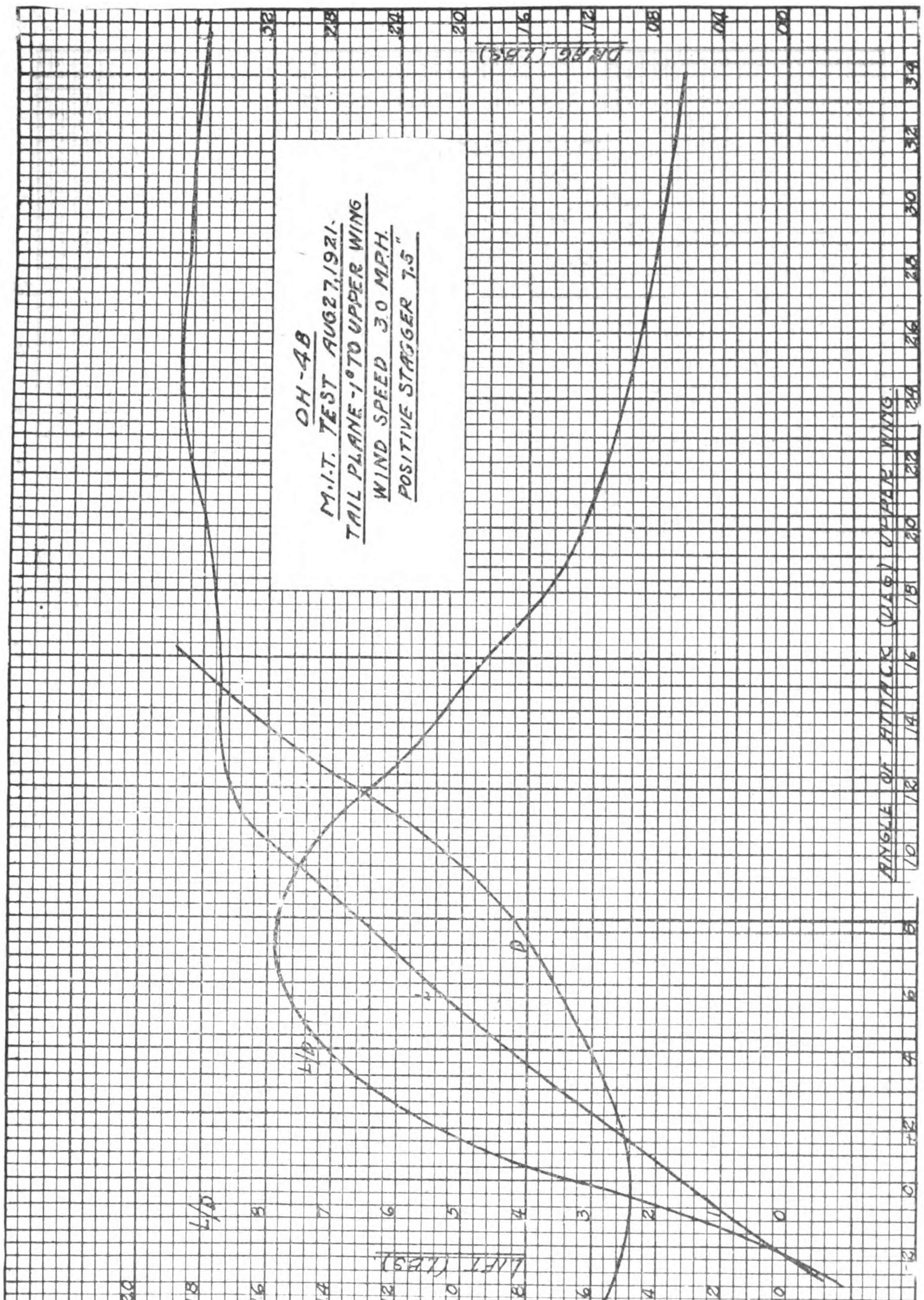

OH-4B
M.I.T. TEST AUG 27, 1921.
TAIL PLANE -1° TO UPPER WING
WIND SPEED 30 M.P.H.
POSITIVE STAGGER 7.5"
DRAG (LBS)
LIFT (LBS)
L/D
ANGLE OF ATTACK (DEG) UPPER WING

FIG. 3.

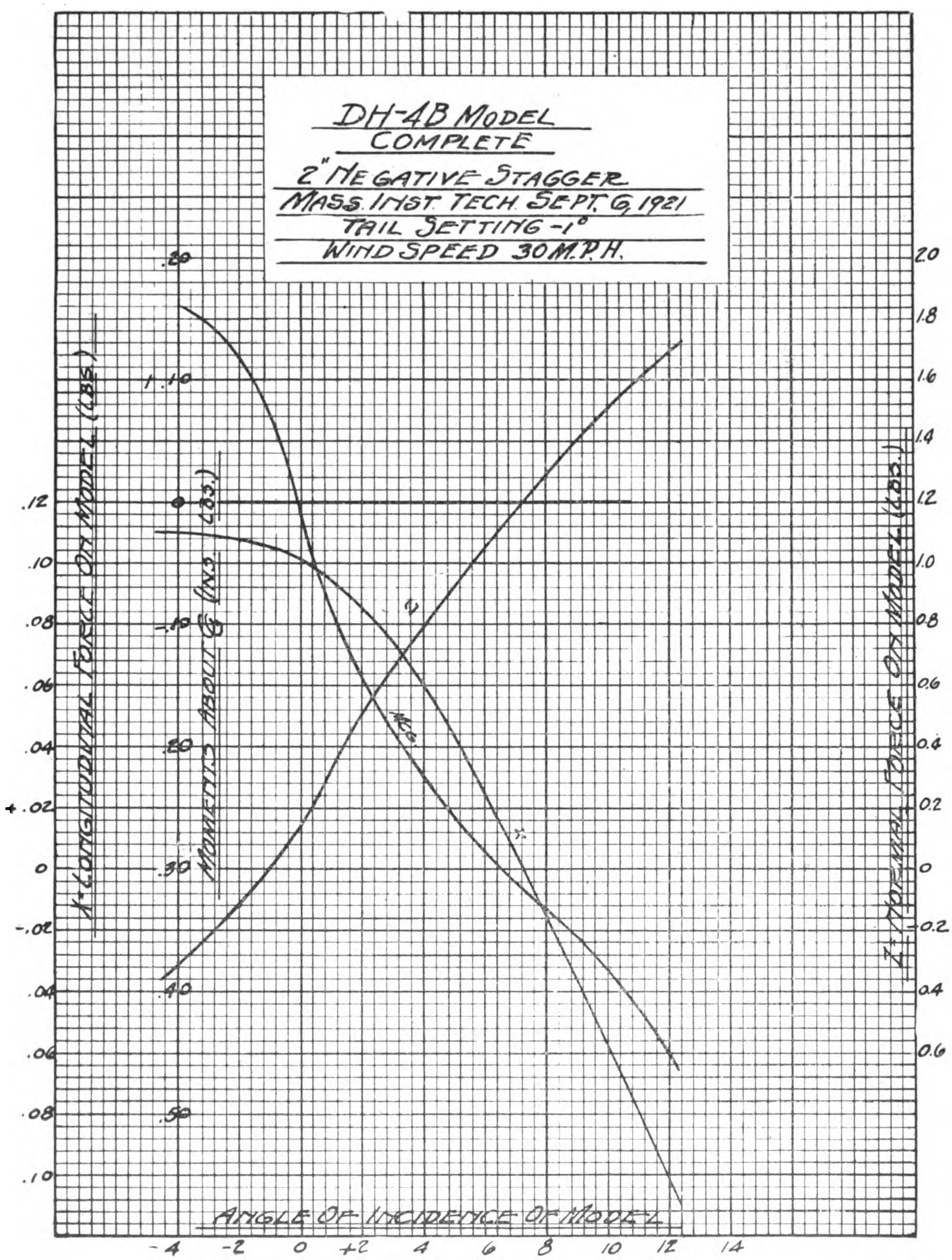

DH-4B MODEL
COMPLETE
2" NEGATIVE STAGGER
MASS. INST. TECH. SEPT. 6, 1921
TAIL SETTING -1°
WIND SPEED 30 M.P.H.
X-LONGITUDINAL FORCE ON MODEL (LBS.)
MOMENTS ABOUT CG (INS. LBS.)
Z-NORMAL FORCE ON MODEL (LBS.)
ANGLE OF INCIDENCE OF MODEL
MCG

FIG. 4.

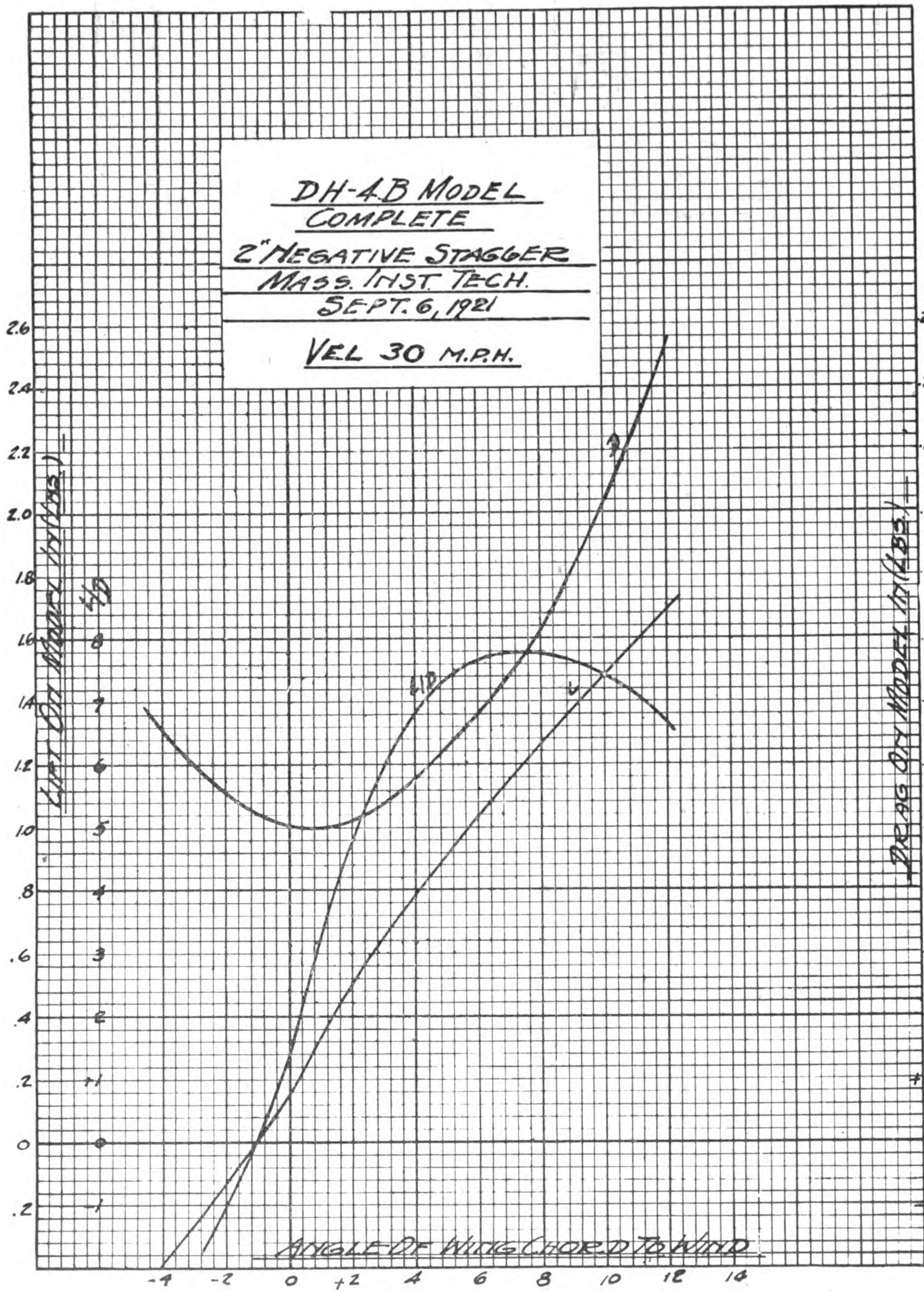

DH-4B MODEL
COMPLETE
2" NEGATIVE STAGGER
MASS. INST. TECH.
SEPT. 6, 1921
VEL 30 M.P.H.
LIFT ON MODEL IN (LBS.)
L/D
DRAG ON MODEL IN (LBS.)
ANGLE OF WING CHORD TO WIND
L/D
L
D
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
.2
8
7
6
5
4
3
2
+1
0
-1
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
+.02
0
.02
-4
-2
0
+2
4
6
8
10
12
14

Fig. 5.

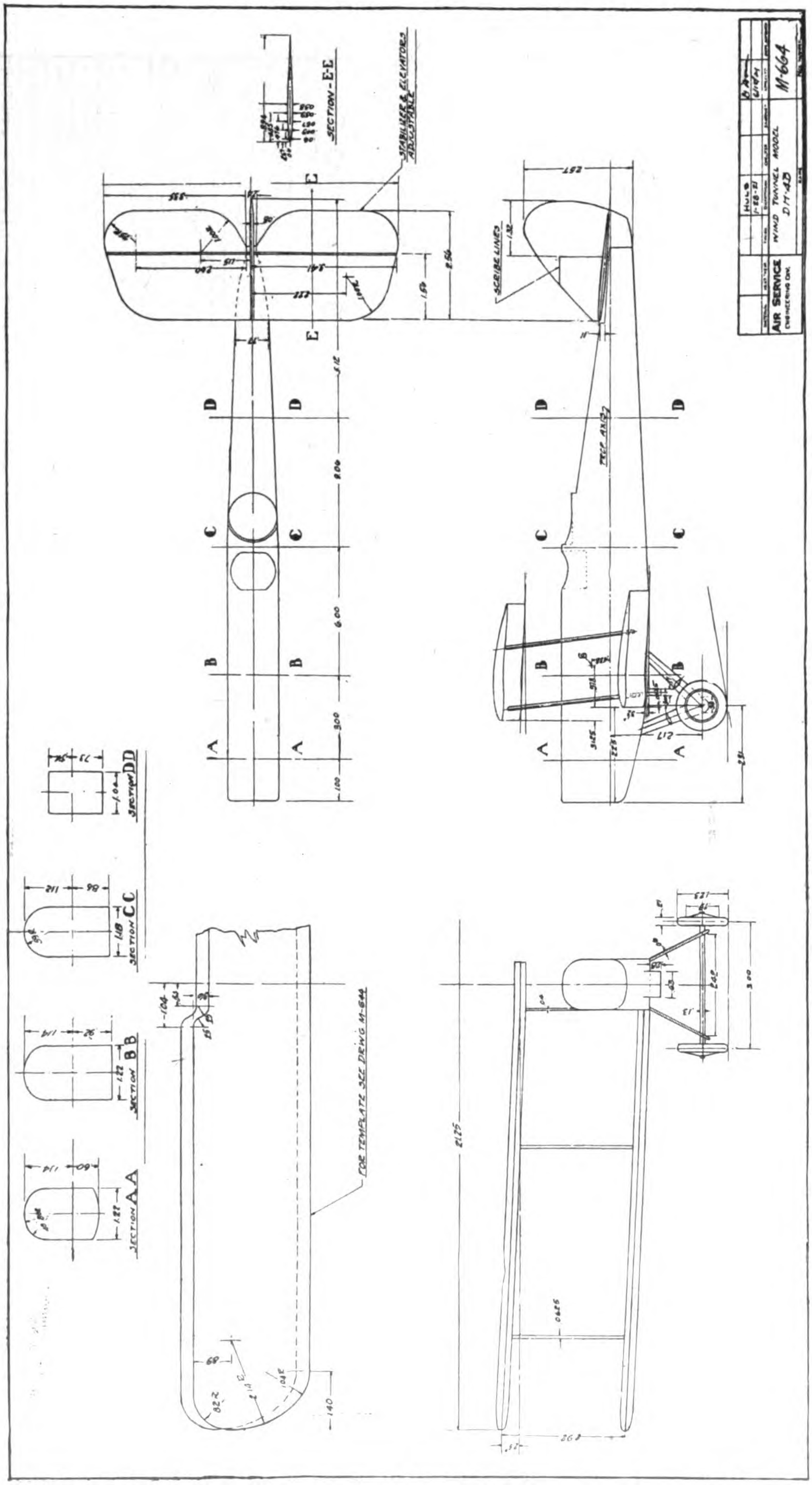

AIR SERVICE
ENGINEERING DIV.
WIND TUNNEL MODEL DH-4B
M-664
SECTION-E-E
STABILIZER & ELEVATORS ADJUSTABLE
SCRIBE LINES
SECTION A A
SECTION B B
SECTION C C
SECTION D D
FOR TEMPLATE SEE DRWG M-644

Fig. 6.

File D 52.41 / 124 *McCOOK FIELD REPORT, SERIAL No. 1869*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV June 15, 1922 No. 356

VARIATION IN VOLUMETRIC EFFICIENCY OF AN ENGINE WITH VALVE LIFT

(POWER PLANT SECTION REPORT)

▽

Prepared by
Capt. T. E. Tillinghast, A. S.
Engineering Division, Air Service
McCook Field, Dayton, Ohio
February 20, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

VARIATION IN VOLUMETRIC EFFICIENCY OF AN ENGINE WITH VALVE LIFT.

OBJECT OF TEST.

The object of these experiments was to determine: (*a*) The effect of changes in valve lift on volumetric efficiency, (*b*) the effect of changes in compression ratio on volumetric efficiency, and (*c*) the effect of changes in valve lift on engine performance.

SUMMARY.

Although experimental difficulties lead to some doubt as to the accuracy of the absolute value of the test results, the following tendencies were clearly shown:

(*a*) Within the limits of this test volumetric efficiency increases with valve lift, the increase being more pronounced as the gas velocity through the inlet valves increases.

(*b*) Under similar conditions a compression ratio of 9.5:1 gives uniformly lower volumetric efficiency than a compression ratio of 5.4:1, except at the lower lifts with one intake valve.

(*c*) In the case of the engine used, the power output increases with increasing valve lift at all speeds from 1,200 to 2,000 revolutions per minute.

CONCLUSIONS.

Since the tests were confined to one particular size and type of cylinder, the results should not be considered as applying generally to all types of cylinders under all conditions. Furthermore, the tests to determine the effect of valve lift on volumetric efficiency were conducted by running the engine with external power and it is possible that the results might be slightly different had the engine been actually firing.

The reduction in volumetric efficiency with an increase of compression ratio is probably accounted for by the fact that the temperature at the end of the compression stroke is much higher in the case of the high compression ratio. This caused the valves and combustion chamber to assume a temperature considerably higher than was the case with the lower compression ratio, and the volumetric efficiency was correspondingly reduced. Whether the higher compression ratio would give a lower volumetric efficiency with the engine running has not been determined.

DESCRIPTION.

The cylinder in Figure 1 having four 1.75-inch valves in a flat cast-iron head, a steel barrel of 5-inch bore, and variable fulcrum valve rocker arms was designed and built for the purpose of ascertaining the effect of valve lift on the performance of an engine. The variable fulcrum arrangement of the valve rockers, as the name implies, provides an adjustment for varying the position of the rocker fulcrum, thereby varying the valve lift. This adjustment is made by turning the knurled knob shown in Figure 1 and can be made while the engine is running. This cylinder was mounted on the Universal test engine, set for a 6-inch stroke. (For a detailed description of the Universal test engine see Engineering Division Report No. 725.)

Figure 2 shows the complete set-up for the volumetric efficiency test. The engine was motored over on the dynamometer, and pumped air from the room through a 2-inch metering orifice (very carefully made in accordance with the instructions contained in Professor Durley's report in the A. S. M. E. Transactions, vol. 27) into chamber "A," which had a square cross section of the dimensions shown. From there it passed through an inch and a half orifice into chamber B, a steel cylinder of 15 cubic feet capacity, and then on through a 2-inch orifice into C, another steel cylinder of 4 cubic feet capacity. The engine pumped directly from C and the volumetric efficiencies were computed on the basis of the existing conditions of temperature and pressure in C. It was assumed that there was no temperature change in the air in passing from the room to C and the temperature was taken in C only. The depression at A was read with an inclined water manometer, and that at C with an upright manometer.

The literature on the general subject of volumetric efficiency of airplane engines is not very extensive. The following references on this subject are suggested.

Mr. H. R. Ricardo's paper delivered in January, 1922, at the winter meeting of the Society of Automotive Engineers in New York City.

"Aero-Engine Efficiencies," by A. H. Gibson, a paper delivered before the Royal Aeronautical Society of Great Britain, 1921.

The volumetric efficiencies obtained on the Liberty and Hispano engines are tabulated in Reports Nos. 102, 103, and 108 of the National Advisory Committee for Aeronautics, Washington, D. C.

LIST OF RUNS MADE.

The pumping runs were made at inlet valve lifts of 0.25, 0.297, 0.36, 0.42, and 0.48 inches with exhaust at maximum lift of 0.516 inches, at 1,200, 1,400, 1,600, 1,800, and 2,000 revolutions per minute. Readings were taken of temperature and of the manometers in A and C (see fig. 1).

The following pumping runs were made:

With a compression ratio of 9.54 to 1 (high compression):
- Three runs with all four valves in operation.
- Two runs with one intake and one diagonally opposite exhaust valve in operation.

With a compression ratio of 5.38 to 1 (low compression):
- Three runs with all four valves in operation.
- Two runs with one intake and one diagonally opposite exhaust valve in operation.

106675—22

A NAS-6 carburetor with a 1.75-inch choke with jets in place was used. No gasoline was fed to the carburetor. It was desired to ascertain the influence, if any, of volumetric efficiency on performance. Accordingly the air measuring apparatus was disconnected, and the carburetor intake opened to the dynamometer room and one friction and one power run, with the four valve low compression set-up, were made at the same valve lifts and revolutions per minute as were used in the pumping tests. The method was to hold the revolution per minute constant, and starting at the minimum valve lift increase it to the maximum and then decrease it to the minimum lift, taking readings of load at the valve lifts corresponding to those used in the volumetric efficiency tests. This obtained two sets of readings at each lift. In these runs the Stromberg NAS-5 carburetor with a 1⅜ inch choke was used. The gasoline was shut off for the friction run.

In all runs, pumping and power, the water outlet temperature was kept at 170° F.

METHODS OF COMPUTATIONS.

R. J. Durley's formula for the flow of air through a flat plate orifice gives the following:

$$W = .01369\ C\ d^2 \sqrt{\frac{iP}{T}}$$

where

- W=weight of gas discharged per second in pounds.
- d=diameter in inches of orifice.
- i=difference in pressures measured in inches of water across orifice.
- P=mean absolute pressure in pounds per square foot across orifice.
- T=absolute temperature of air Fahrenheit.
- C=experimental coefficient of discharge (0.600 in the case of a 2-inch diameter orifice).

Professor Durley in all of his experiments measured flow discharging in to the atmosphere, while in these experiments it was necessary that the flow be measured from the atmosphere. In Technical Notes No. 40 of the National Advisory Committee for Aeronautics, are the results of experiments made to determine the effect of the reversal of flow upon the discharge coefficient of Durley orifices, which indicate that the discharge coefficient is not reduced by more than 1 per cent, which is probably within the experimental error of Durley's experiments. Therefore, no attempt was made to correct for reversal of flow through the orifice in these experiments.

The pounds of air per second pumped, as obtained by Durley's formula, were changed to cubic feet per second under existing conditions of temperature and pressure at C. This volume divided by the piston displacement of the engine in cubic feet per second gave the volumetric efficiency of the engine.

ANALYSIS.

The apparatus used in the volumetric efficiency tests did not succeed in wholly dampening out the pulsations in the 4-valve arrangement of the engine. The inclined manometer measuring drop in pressure across the metering orifice remained quite steady, but pulsations sufficient to make an error as great as 1 per cent frequently occurred, particularly at higher speeds in the manometer at C. Care was taken to read the manometers only when they were steady. There were no pulsations in the 2-valve arrangement.

The results of the volumetric efficiency tests with the 4-valve arrangement, at the lower compression ratio, are shown in Figure 3. The volumetric efficiencies of three runs are plotted against valve lift and valve area for the different revolutions per minute, and a mean curve drawn through the points. (The area of opening per valve was taken as the area of a cylinder whose diameter is the inside diameter of valve seat and whose height is the maximum valve lift.)

The results of the same set-up with the higher compression ratio are shown in Figure 4. Figure 5 shows the resultant curves of Figures 3 and 4 plotted together on the same sheet for the purpose of comparison. It will be noticed that the volumetric efficiency of the low-compression runs is consistently higher than that of the high compression. On all high-compression runs of the 4-valve arrangement, sufficient heat was generated during the compression stroke to partially burn the oil which entered the combustion chamber. No such effect was noticed during the low-compression runs. The most probable explanation for the consistently higher efficiencies of the low-compression set-up is that an increase in temperature of the combustion chamber lowers the efficiency. It will be remembered that the amount of air pumped was measured in terms of the conditions of air at the carburetor intake.

Varying the valve lift seems to have the same effect in both high and low compression runs. There is but a slight increase in efficiency obtained in increasing valve lift at 1,200, 1,400, or 1,600 revolutions per minute, and at 1,200 and 1,400 revolutions per minute there is a slight decrease at the maximum lift, while there is a decided gain in efficiency at 1,800 and 2,000 revolutions per minute. This may be due to valve timing, for the efficiencies increase up to 1,800 revolutions per minute, where they begin to fall off. This might indicate that the combination of valve timing and manifold length was best suited for a speed in the neighborhood of 1,800 revolutions per minute. The valve timing obtained with the engine cold was as follows: Inlet opens 12° after top center, closes 32° after bottom center; exhaust opens 30° before bottom center, closes 6° after top center.

Figure 6 shows the results of high and low compression runs with the 2 valves in head arrangement. Here there is a decided increase in efficiency with increased valve lift at all speeds. At all speeds with the exception of 1,200 revolutions per minute the low-compression runs show a greater efficiency at the higher valve lifts.

In Table 5 are the loads measured on a 15.75-inch torque arm, obtained in running the engine under its own power, and also the loads required to motor the engine over at the same conditions of valve lift and revolutions per minute. Due to very frequent failure of the exhaust valves throughout the tests, using up the supply on hand, only one friction and one power run were obtained, the last valve breaking just at the completion of the power run.

The indicated load in Table 5 was obtained by adding the power and friction loads. An attempt was made with the data on hand to determine whether or not there was any relation between indicated power and volumetric

efficiency. Figure 7 shows the change in indicated loads, and volumetric efficiencies at the different revolutions per minute plotted against valve lift. All that can really be definitely determined from these curves is that both power and volumetric efficiency tend to increase with increase in valve lift.

Due to continual mechanical failures in the engine, the period of the test covered approximately two months, and in all cases several days necessarily elapsed between runs. In spite of the care with which readings were taken (and as has been previously stated, the pulsations in the manometers could account for an error of only 1 per cent), runs taken on different days failed to agree within sometimes as great an amount as 6 per cent.

In view of the fact that this investigation was confined to the performance of one size and type of cylinder unit, the results may not hold true for all types of cylinders under all conditions. Further, since the effect of valve lift on volumetric efficiency was determined by operating the engine as a pump (i. e., running it under external power), it is possible that slightly different results might have been obtained had the engine been actually firing.

The observed reduction in volumetric efficiency with increase of compression ratio may be accounted for by the fact that the temperature at the end of the compression stroke is much higher in the case of the high compression ratio. This caused the temperature of the valves and combustion chamber to be considerably higher than was the case with the lower compression ratio. The volumetric efficiency was correspondingly reduced, but whether this reduction would obtain with the engine running has not been determined.

The results of the comparison of the rates of increase of indicated load and the volumetric efficiency indicate merely that as valve lift is increased, indicated horsepower and volumetric efficiency also increase.

TABLE 1.—*Volumetric efficiencies.*

FOUR VALVES, LOW COMPRESSION RATIO, RESULTS OF THREE RUNS.

R. p. m.	Efficiencies at valve lifts.														
	0.250			0.297			0.360			0.420			0.480		
	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.
1,200	86.9	88.5	89.2	87.3	91.5	88.7	88.8	92.3	89.7	86.8	93.0	91.7	87.9	93.1	89.7
1,400	91.5	91.2	94.1	91.6	91.6	94.3	92.4	93.5	94.3	83.8	93.0	94.8	92.9	92.5	94.4
1,600	91.8	90.0	94.2	95.5	94.1	95.5	94.3	95.6	96.4	94.0	95.9	96.9	96.0	95.4	97.5
1,800	91.9	89.4	92.9	96.4	93.7	94.6	99.0	95.7	98.0	99.8	97.2	98.7	99.7	97.7	99.0
2,000	85.4	85.2	87.5	90.6	91.1	91.5	95.2	93.0	94.6	95.8	94.0	96.4	95.9	94.6	97.1

TABLE 2.—*Volumetric efficiencies.*

FOUR VALVES, HIGH COMPRESSION, RESULTS OF THREE RUNS.

R. p. m.	Efficiencies at valve lifts.														
	0.250			0.297			0.360			0.420			0.480		
	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.
1,200	88.9	85.9	86.4	88.1	85.2	88.5	88.9	86.5	88.5	89.5	87.7	90.6	88.9	87.7	89.3
1,400	90.0	86.5	90.4	89.0	88.0	91.0	90.8	89.4	91.0	90.1	89.6	91.8	89.4	89.0	92.6
1,600	91.6	88.3	92.5	92.1	88.3	94.0	93.3	91.9	94.0	93.8	92.3	94.0	93.9	93.0	94.4
1,800	91.8	86.4	93.6	94.0	90.6	95.8	96.5	92.8	98.7	97.2	95.4	99.0	97.2	95.3	99.6
2,000	86.6	83.8	89.0	90.8	88.2	92.3	93.5	90.0	94.6	94.0	93.2	94.7	94.0	92.8	95.0

TABLE 3.—*Volumetric efficiencies.*

TWO VALVES, HIGH COMPRESSION RATIO, RESULTS OF TWO RUNS.

R. p. m.	Efficiency at valve lifts.									
	0.25		0.297		0.36		0.42		0.48	
	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.
1,200	82.1	81.5	88.6	86.2	89.7	86.5	90.7	90.8	91.5	90.8
1,400	78.8	77.9	82.7	82.4	87.8	87.1	87.7	88.0	89.7	88.4
1,600	71.9	72.2	79.9	79.3	84.1	83.0	86.6	86.2	89.6	89.4
1,800	67.2	67.1	75.9	75.7	82.4	82.6	85.8	85.7	87.9	87.2
2,000	62.0	62.1	73.3	72.2	77.7	76.8	82.2	81.5	84.0	83.1

TABLE 4.—*Volumetric efficiencies.*

TWO VALVES, LOW COMPRESSION RATIO, RESULTS OF TWO RUNS.

R. p. m.	Efficiency at valve lifts.									
	0.25		0.297		0.36		0.42		0.48	
	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.
1,200	82.7	81.9	91.6	87.2	90.6	88.65	92.6	88.8	90.5	92.6
1,400	75.2	75.5	84.4	84.1	88.7	86.7	90.3	89.6	91.0	91.3
1,600	71.0	71.1	78.8	79.2	84.5	87.2	87.0	90.1	90.5	92.0
1,800	65.4	60.9	74.2	76.6	80.4	83.4	86.1	86.6	92.4	89.5
2,000	62.0	59.2	68.5	68.6	76.0	77.5	82.1	81.4	87.6	84.3

TABLE 5.—*Rates of change of indicated load and volumetric efficiency at various r. p. m. and valve lifts for the four-valve low compression ratio set-up.*

1,200 R. P. M.

Valve lift (inches).	Power load (lb. at 15¾ in.).	Friction load (pound).	Indicated load (pound).	Per cent change indicated load.	Per cent change in volumetric efficiency.
0.25	66.05	16.40	82.45	0	0
.297	67.80	16.50	84.30	2.2	1.5
.36	68.05	16.45	84.50	2.5	3.0
.42	68.30	16.50	84.80	3.0	3.5
.48	69.20	16.70	85.90	4.2	2.6

1,400 R. P. M.

0.25	66.05	17.10	83.15	0	0
.297	67.80	16.90	84.70	1.9	0.5
.36	68.70	16.85	85.55	2.9	1.6
.42	69.90	16.80	86.70	4.3	2.3
.48	70.00	16.90	86.90	4.5	2.8

1,600 R. P. M.

0.25	60.50	19.75	80.25	0	0
.297	63.20	19.50	82.70	3.0	2.1
.36	64.80	19.45	84.25	5.0	3.8
.42	64.80	19.40	84.20	4.9	3.8
.48	65.90	19.40	85.30	6.3	4.3

1,800 R. P. M.

0.25	58.20	19.45	77.65	0	0
.297	61.80	19.10	80.90	4.2	4.4
.36	62.70	19.20	81.90	5.5	7.1
.42	64.05	18.80	82.85	6.7	7.6
.48	64.30	18.80	83.10	7.0	7.9

2,000 R. P. M.

0.25	52.80	20.45	73.25	0	0
.297	56.60	19.90	76.50	4.4	5.5
.36	57.40	19.80	77.20	5.4	9.3
.42	58.00	19.75	77.75	6.1	10.0
.48	58.90	19.90	78.80	7.6	10.0

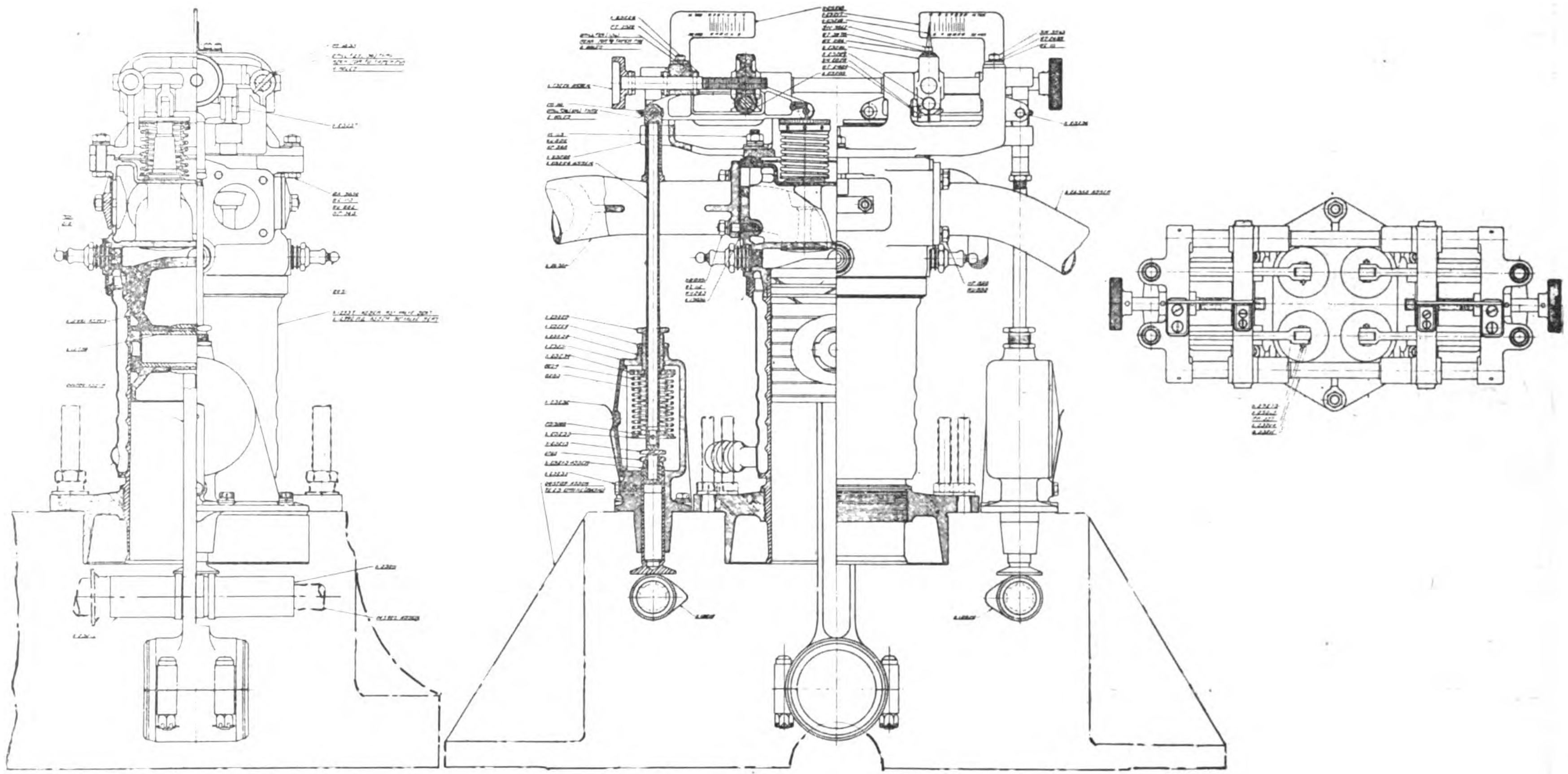


FIG. 1.—Volumetric efficiency test. Variable fulcrum valve mechanism assembly.

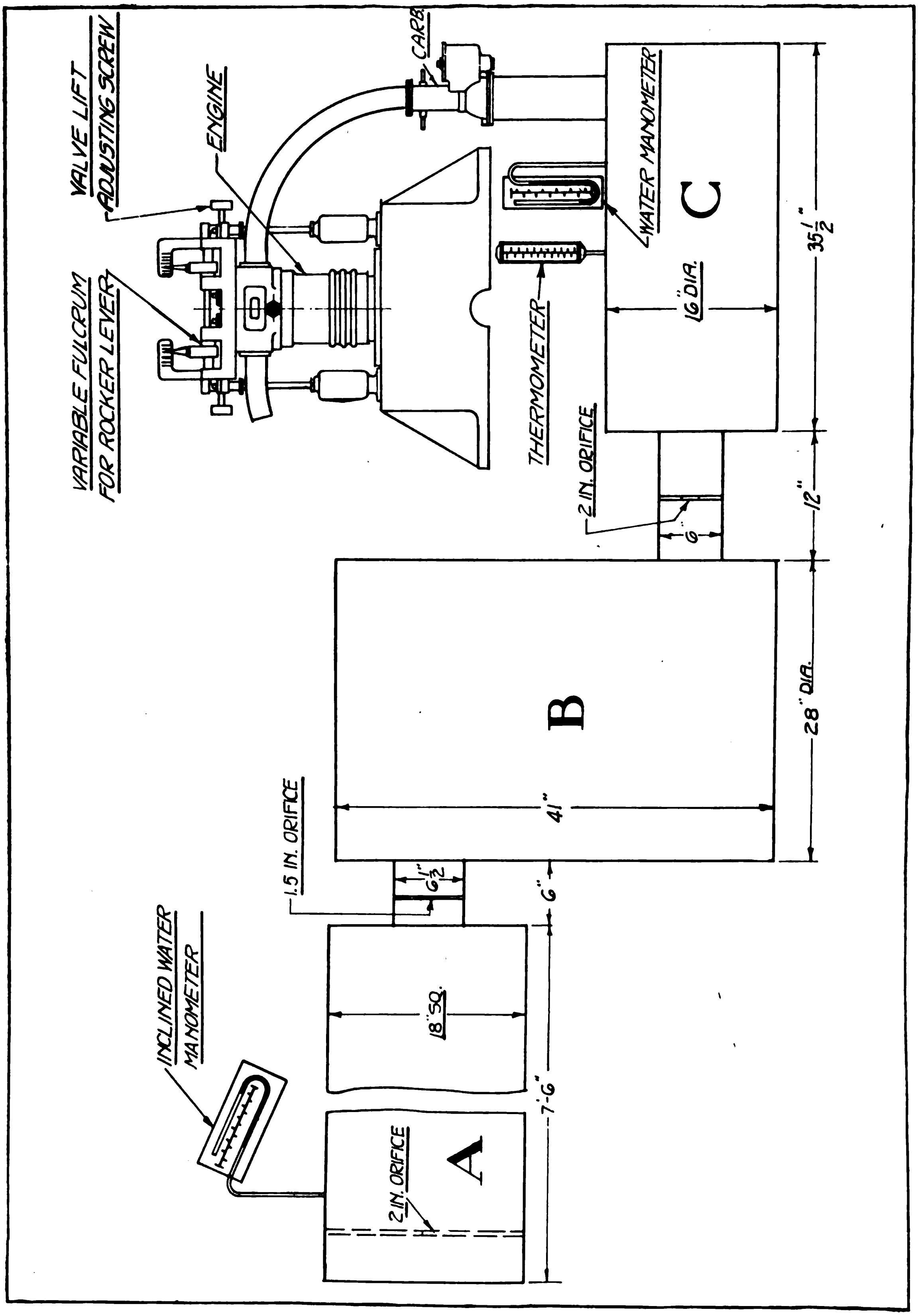

VALVE LIFT
ADJUSTING SCREW
ENGINE
CARB.
VARIABLE FULCRUM
FOR ROCKER LEVER
WATER MANOMETER
C
16" DIA.
35 1/2"
THERMOMETER
2 IN. ORIFICE
6"
12"
B
41"
28" DIA.
1.5 IN. ORIFICE
6 1/2"
6"
INCLINED WATER
MANOMETER
18" SQ.
7'-6"
A
2 IN. ORIFICE

FIG. 2.

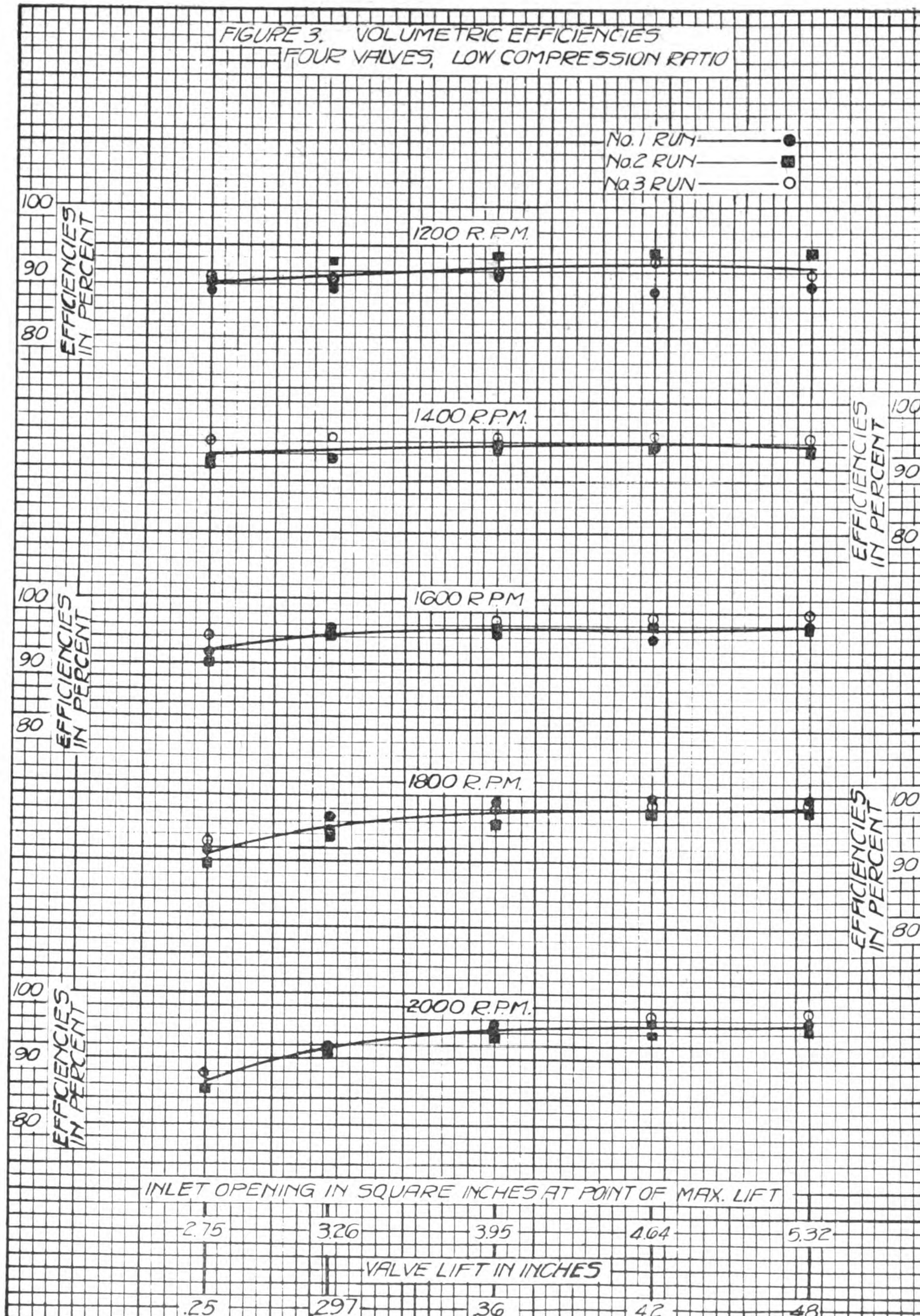


FIGURE 3. VOLUMETRIC EFFICIENCIES
FOUR VALVES, LOW COMPRESSION RATIO
No. 1 RUN
No. 2 RUN
No. 3 RUN
1200 R.P.M.
1400 R.P.M.
1600 R.P.M.
1800 R.P.M.
2000 R.P.M.
EFFICIENCIES IN PERCENT
100
90
80
INLET OPENING IN SQUARE INCHES AT POINT OF MAX. LIFT
2.75
3.26
3.95
4.64
5.32
VALVE LIFT IN INCHES
.25
.297
.36
.42
.48

FIG. 3.

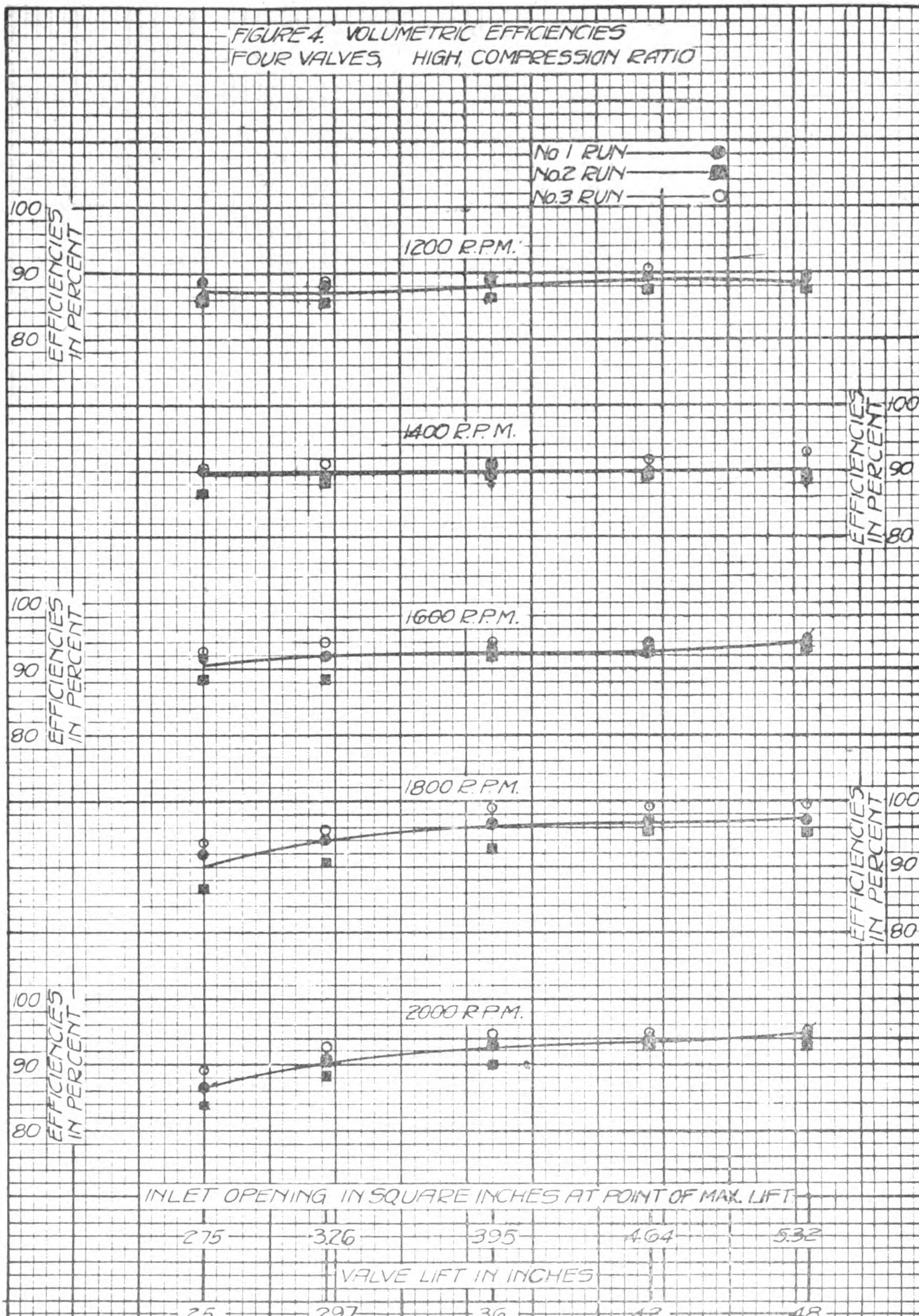


FIGURE 4. VOLUMETRIC EFFICIENCIES
FOUR VALVES, HIGH COMPRESSION RATIO
No 1 RUN
No.2 RUN
No.3 RUN
1200 R.P.M.
1400 R.P.M.
1600 R.P.M.
1800 R.P.M.
2000 R.P.M.
EFFICIENCIES IN PERCENT
100
90
80
INLET OPENING IN SQUARE INCHES AT POINT OF MAX. LIFT
.275
.326
.395
.464
.532
VALVE LIFT IN INCHES
.25
.297
.36
.42
.48

FIG. 4.

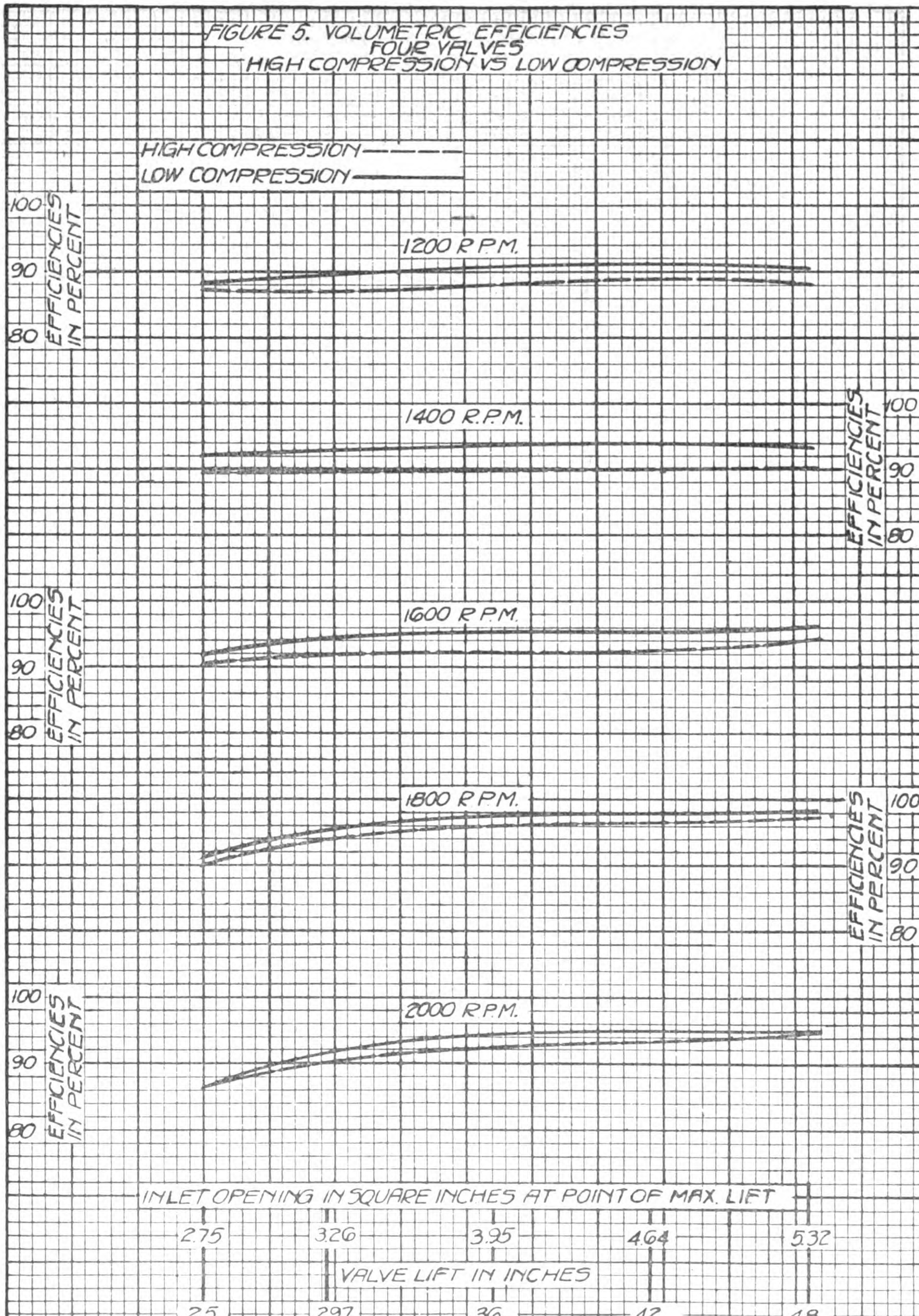


FIGURE 5. VOLUMETRIC EFFICIENCIES
FOUR VALVES
HIGH COMPRESSION VS LOW COMPRESSION
HIGH COMPRESSION
LOW COMPRESSION
1200 R.P.M.
1400 R.P.M.
1600 R.P.M.
1800 R.P.M.
2000 R.P.M.
EFFICIENCIES IN PERCENT
100
90
80
INLET OPENING IN SQUARE INCHES AT POINT OF MAX. LIFT
2.75
3.26
3.95
4.64
5.32
VALVE LIFT IN INCHES
.25
.297
.36
.42
.48

Fig. 5.

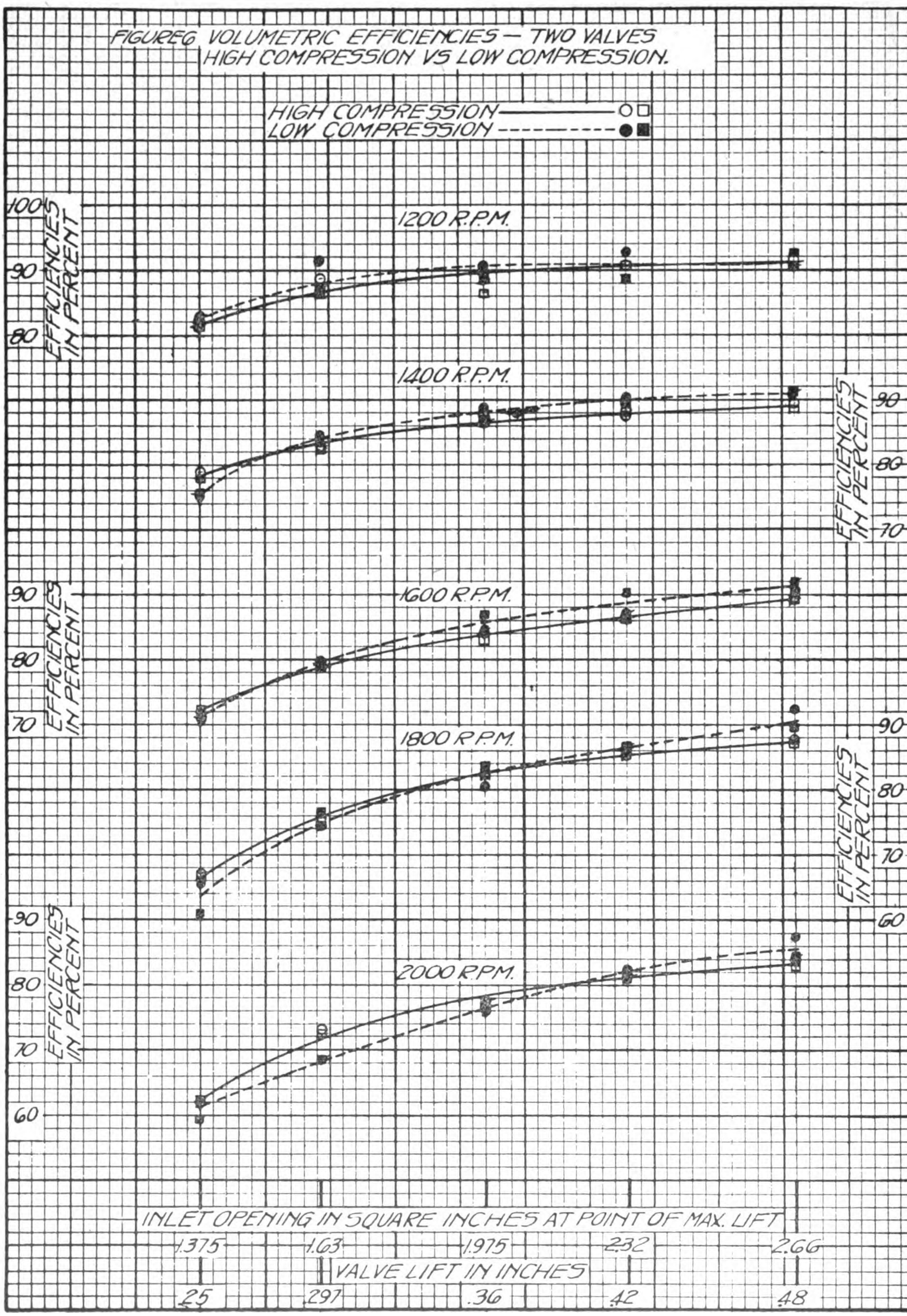


FIGURE 6 VOLUMETRIC EFFICIENCIES — TWO VALVES
HIGH COMPRESSION VS LOW COMPRESSION.
HIGH COMPRESSION
LOW COMPRESSION
1200 R.P.M.
1400 R.P.M.
1600 R.P.M.
1800 R.P.M.
2000 R.P.M.
EFFICIENCIES IN PERCENT
INLET OPENING IN SQUARE INCHES AT POINT OF MAX. LIFT
1.375
1.63
1.975
2.32
2.66
VALVE LIFT IN INCHES
.25
.297
.36
.42
.48

FIG. 6.

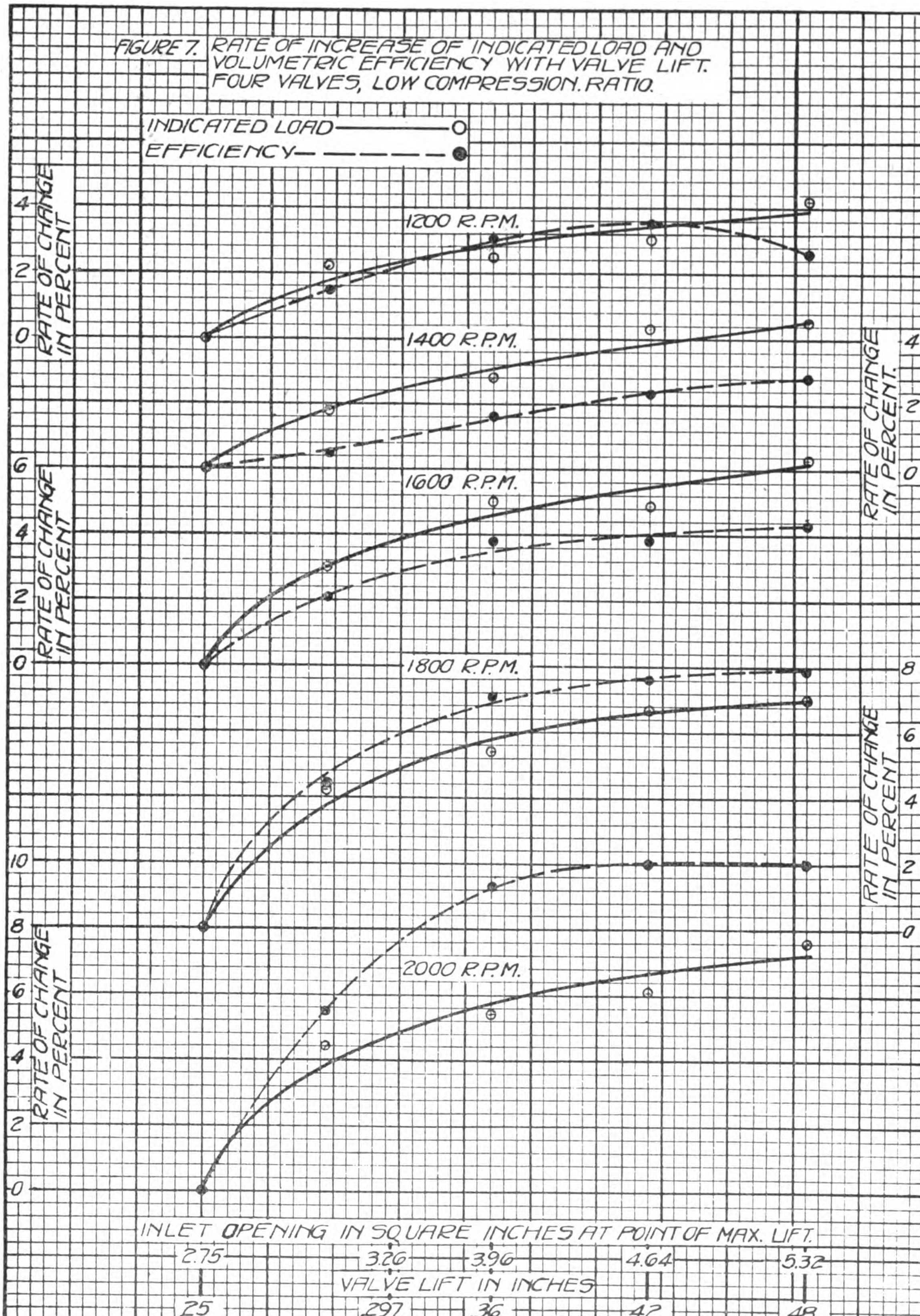


FIGURE 7. RATE OF INCREASE OF INDICATED LOAD AND VOLUMETRIC EFFICIENCY WITH VALVE LIFT. FOUR VALVES, LOW COMPRESSION. RATIO.
INDICATED LOAD
EFFICIENCY
1200 R.P.M.
1400 R.P.M.
1600 R.P.M.
1800 R.P.M.
2000 R.P.M.
RATE OF CHANGE IN PERCENT
INLET OPENING IN SQUARE INCHES AT POINT OF MAX. LIFT.
2.75
3.26
3.96
4.64
5.32
VALVE LIFT IN INCHES
.25
.297
.36
.42
.48

FIG. 7.

File D 52.415/29 h1 *McCOOK FIELD REPORT, SERIAL No. 1883*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | July 15, 1922 | No. 357

REPORT ON TEST OF BIJUR IGNITION END STARTER FOR AIRPLANE ENGINES

(EQUIPMENT SECTION REPORT)

▽

Prepared by
J. W. Allen, A. M. E.
Engineering Division, Air Service
McCook Field, Dayton, Ohio
March 25, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

TEST OF BIJUR IGNITION END STARTER FOR AIRPLANE ENGINES.

OBJECT.

The object of this test was to determine the characteristics and performance of the Bijur rear end starter.

DATE AND PLACE.

The tests were conducted by the Electrical Branch, Equipment Section, McCook Field, Dayton, Ohio, over a period of about nine months, ending August, 1921.

DESCRIPTION AND DIMENSIONS.

Figures 5, 6, and 7, respectively, show views of an assembled starter.

Figure 1 gives the outline dimensions.

Table 4 gives the weights of a starter and accessories.

Figure 16 shows the starter as installed on a Liberty "12" airplane engine.

Figure 10 is a view of the motor and reduction gear housing.

Figures 8 and 9 show the assembly of the back-fire release mechanism and main bearing.

Figures 11 and 14 show disassembled view of the back-fire release mechanism.

Figure 12 shows disassembled view of planetary reduction gearing.

In the following explanation of the action of the starter, the cross section view (see Fig. 2) can be used to advantage.

As soon as the series starting motor is energized, the bevel pinion, shown in position in Figure 10, begins to revolve. This pinion meshing with the bevel gear, shown in Figure 12, causes the planetary gear system to revolve, at a reduction of 4.5 to 1. The idler gears, shown in position in the planetary gear assembly, Figure 12, and disassembled in part 4 of Figure 14, being in mesh with the fixed internal gear, part 8, Figure 14, and the free internal gear, part 8, Figure 14, cause the free internal gear, Figure 14, to revolve, at a reduction of 23.1. The total gear reduction from motor bevel pinion to the driving barrel is 103.5 to 1. The free internal gear being integral with the driving barrel, part 2 of Figure 14 causes the entire back-fire release mechanism, as shown in Figure 8, to revolve.

The friction disks, parts 6 and 9 of Figure 14, shown in position in Figures 7 and 9 tend to keep the spline screw, part 3, Figure 11, from revolving. The spline nut, part 1, Figure 11, being in mesh with the thread of the spline screw tends to revolve the spline screw. As a resultant, the spline screw is forced out of the spline nut and assumes a position with respect to the starter, as shown in Figure 5. With the spline screw in this emerged position, it is in mesh with the spline on the crank shaft of the engine being started. The spline screw is kept from emerging further because of a nut, part 7 of Figure 11, which bears against a shoulder in the driving barrel, part 2 of Figure 14. The compression washers, part 5 of Figure 11, being between the inside shoulder of the driving barrel, part 2 of Figure 14, and the radially projecting lugs on the spline nut, prevent the spline nut from advancing along the spline screw toward the threaded end of the spline screw. However, if the spline screw should be held stationary, by virtue of an extremely stiff engine, the spline nut would advance along the spline screw, compressing the compression washers. A point would be reached where the projecting lugs of the spline nut would draw out of the spline plate, part 1 of Figure 14, and thereby allow the driving barrel to rotate in its normal direction. As the next spline in the spline plate comes along, the compression washers tend to force the spline nut into its normal position. This it does with a click because of clearance between splines and also because of the release of torsion on shaft.

If the starter circuit is not interrupted, the clicking continues at regular intervals. The starter should be interrupted as soon as the first click is heard. A continued operation of this, the back-fire release, wears the edges off the spline plate and spline nut projections, causing the back-fire release mechanism to operate at a lower torque. The manner in which the projections are worn away can be easily seen in part 1, Figure 14, the upper portions of the projections having been rounded off under the action.

The back-fire release mechanism is designed to function at about 600 pounds feet torque. This torque is more than sufficient to turn over a cold Liberty "12" engine.

In starting, if the engine should back-fire, the back-fire release mechanism will operate, thus protecting both starter and engine.

PROCEDURE.

The following tests were made on a sample Bijur ignition end starter:

1. Operation at no load.
2. Characteristics under various loads.
3. Performance when subjected to back-fires.

For operation at no load a 12-volt storage battery was connected across the starter motor terminals, through a suitable switch. The amperes input, voltage and spline screw revolutions were noted. Data are recorded in Table 1.

The operation of the spline screw was observed. Before the starter switch was closed the spline was forced back into the spline nut. The switch was then closed and the action of the spline screw observed. The action was immediate and continuous, the spline screw emerging with no apparent delay.

The starter was then attached to a Prony brake, so that the output at the spline screw could be measured, by

means of an arm and a scale. The loading was increased by increasing the friction between the brake band and the brake. Figure 3 shows the Prony brake and manner of attaching the starter.

The power supply consisted of four 12-volt, 60-ampere hour storage batteries connected in multiple.

The test consisted of loading the starter in successive steps. For each loading armature amperes, volts across the motor terminals, revolutions of brake drum, and the weight at torque arm were recorded.

Data are recorded in Table 2. Sketch of connections are shown in Figure 3.

Characteristic curves of the performance are shown in Figure 4.

The starter was then mounted on a Liberty "12" engine. The source of power was one 12-volt, 60-ampere hour storage battery. The spark of the engine was so manipulated that while the engine was being turned over by the starter, the engine would back-fire. Such back-fire would cause the back-fire release mechanism to operate. As the engine back-fired, the torque exerted by the starting motor was sufficient to cause the engine to stall. At no time did the back-fire cause the back-fire release mechanism to release past more than one spline. The starter was subjected to 10 distinct back-fires.

After the back-fires, the starter was disassembled and an examination of the parts was made to determine the effect of the back-fires on the starter parts. The only effect noticeable was a wearing of the spline nut and spline plate splines, as shown in the photograph of the spline plate in Part 1 of Figure 14.

TABULATION OF DATA AND RESULTS.

Data of no load operation of starter are tabulated in Table 1.

Data of operation of starter under different loads are tabulated in Table 2.

Table 4 gives the weights of starter and accessories for a starter installation.

Data of performance of starter when subjected to back-fires are tabulated in Table 3.

DISCUSSION.

The first starter, used to any appreciable extent on Liberty "12" engines, was the Bijur propeller end starter. Although having the necessary power, it had several undesirable features.

1. The engagement was not positive. The engaging action depended on the speed of the motor and the inertia of the pinion shaft. This required a minimum of friction between the screw shaft and the spline nut. Any particles of dirt getting in on the bearing surface between the barrel drive and the pinion shaft, or in the screw of the screw shaft and spline nut, tended to cause the pinion shaft to turn with the barrel drive before it emerged far enough to mesh with the starting motor gear.

2. Due to location of starter, dirt particles sifted into all working parts and prevented the efficient operation of the starter.

3. The propeller end starter had no protection against back-fires or heavy overloads.

4. The location at the propeller end was a drawback for several reasons, namely:

(*a*) It required a special radiator.

(*b*) It could not be used with a supercharger.

(*c*) It required a longer length for connection to the battery.

(*d*) To change a propeller end starter necessitated the removal of the radiator each time.

Having the above points in view, the Bijur Motor Appliance Co. agreed to develop a starter for the Engineering Division which could be mounted on the ignition end of the Liberty "12" engine, and which would also include the following features:

1. A more positive engagement.
2. The chance for dust particles getting into the working parts reduced to a minimum.
3. A back-fire release, or overload protective device.
4. The ignition end location.

This enabled starters to be installed or changed easily and at the same time required a shorter length of cable for connection to the battery.

The Bijur Motor Appliance Co., accordingly, submitted several experimental models for test. The operating characteristics of these were very favorable and, with several recommended mechanical changes were considered as satisfactory for production. An engineering report (see Air Service Information Circular, Vol. I, No. 22) to this effect was made.

In March, 1920, a production order, No. 530037, was issued by the Procurement Section, Washington, D. C., for 590 Bijur ignition end starters.

Six starters built on Production Order No. 530037 were delivered to this division for acceptance tests on or about February 15, 1921. Five of these starters showed a premature functioning of the back-fire release as determined by attempts to turn over a cold Liberty "12" engine on the torque stand. When placed on a Prony brake for torque test, they all showed an average release point of about 360 pound-feet.

On back-fire, also a few while being tested on Prony brake showed a structural weakness in the driving barrel, as well as in the spline plate. These parts fractured under operation of the back-fire release mechanism.

A letter was written February 23, 1921, to the chief of Air Service, regarding the faults as brought out by these tests.

The Bijur Motor Appliance Co. went after the trouble and as a result made several changes that have enabled the starters to perform their function satisfactorily. They changed the pitch of the screw shaft and spline nut, which remedied the premature functioning of the back-fire release. The fractures of driving barrel were due to heat treatment, which has been eliminated.

About June 1, 1921, six starters with improved spline nut, screw shaft, and driving barrel were subjected to 10 back-fires each, after torque curves to stall had been taken on each one. Four of these, on back-fire, stalled the engine without releasing more than once or twice. On the fifth one, the back-fire release mechanism operated 10 times with 2 complete stalls. The sixth one jammed completely. Upon disassembly, the fifth one showed a worn edge on the spline plate, allowing the back-fire device to release a little earlier; otherwise it was satisfactory. The

sixth one jammed because of a broken idler stud causing a jamming of the idlers in the internal gearing. A sample of the broken spline plate, driving barrel, and the idler stud are shown in figure 15.

It is considered that the improved starters, as tested, are very satisfactory. It is reasonably felt that the breakage of spline plates and driving barrels has been reduced to a minimum, while the failure of the idler stud is considered a rare failure.

There is no question of the ability of the Bijur ignition end starter to turn over a Liberty "12" high compression airplane engine. Even in cold weather, the starter functioned and turned over the engine. The weather referred to is at Dayton, Ohio, and this winter (1921-22), the temperature has been between 5° F. and 10° F. several times.

The mounting of the starter is very simple. All that is required is to remove the rear crank-case cover plate and screw in 3/8-24 studs, 1¾ inches long in all but the top tapped hole, the starter flange being drilled to correspond, is slipped over the studs and the starter fastened in place. No lining up of the spline screw with the spline gear on the crank-shaft is necessary. All connections from the battery to the starter must be made with No. 00 stranded cable, double wrapped with varnished cambric (United States Spec. No. 27074), and covered with a double cotton braid. This size cable is necessary because of the high current taken by the starter motor (under load), and also to keep the voltage drop in the cables to a minimum.

The choice between a manually and a magnetically operated switch depends on the distance between the battery and the starter and should be made as short as is possible. A magnetically operated switch should be used whenever at least 3½ feet of No. 00 cable can be saved by so doing. If the starter circuit must pass near the pilot, the manually operated switch is more economical of weight, providing the switch can be installed where it can be readily reached by the pilot.

CONCLUSION.

The Bijur ignition end starter is well suited for use in airplanes to turn over a Liberty "12" engine at starting for the following reasons:

1. It is compact.
2. It is light in weight.
3. It has ample power.
4. It is very easily attached.
5. It eliminates danger to mechanic at starting.
6. Its use enables cross-country flights without danger of stalling at some out-of-way location, because of lack of manual help for starting. This is especially true of a forced landing in some out-of-the-way location.

TABLE 1.—*Bijur ignition end starter characteristic curves.*

Amperes.	Volts.	Watts input.	No load.		Watts output.	Per cent efficiency.
			Revolutions per minute.	Torque.		
70	11.8	827	87	....	....	....

TABLE 2.—*Load characteristics.*

Amperes.	Volts.	Watts input.	No load.		Watts output.	Per cent efficiency.
			Revolutions per minute.	Torque.		
164	11.2	1,836	49	52	357	19.4
200	10.85	2,263	40.3	108	510	26.9
229	10.7	2,450	37.3	140	731	29.8
261	10.5	2,740	33.4	188	884	32.2
286	10.35	2,960	31.0	224	975	32.9
322	10.18	3,280	28.3	272	1,080	32.9
335	10.10	3,385	27.3	288	1,104	32.6
403	9.77	3,940	23.7	372	1,236	31.3
459	9.50	4,360	21.2	436	1,298	29.8
513	9.22	4,730	18.8	500	1,320	27.9
574	8.87	5,090	16.5	572	1,324	26.0
632	8.5	5,370	14.0	644	1,262	23.5
880	6.8	5,990	0	800	....	....

TABLE 3.—*Results of back-fires on starter.*

Engine stalled eight times.
Back-fire release operated three times.
Result.—Splines of spline plate and spline nut worn a little.

TABLE 4.—*Weight of starter installation.*

	Pounds.
Bijur ignition end starter	30.80
Four feet No. 00 flexible copper cable	2.18
Manually operated switch	1.20
Cable terminals (minimum of four needed)	.252
Total	34.432
Magnetically operated switch	2.70
Push button for magnetic switch	.26
Push button wire (20 feet)	.276
Weight of magnetic switch accessories	3.236

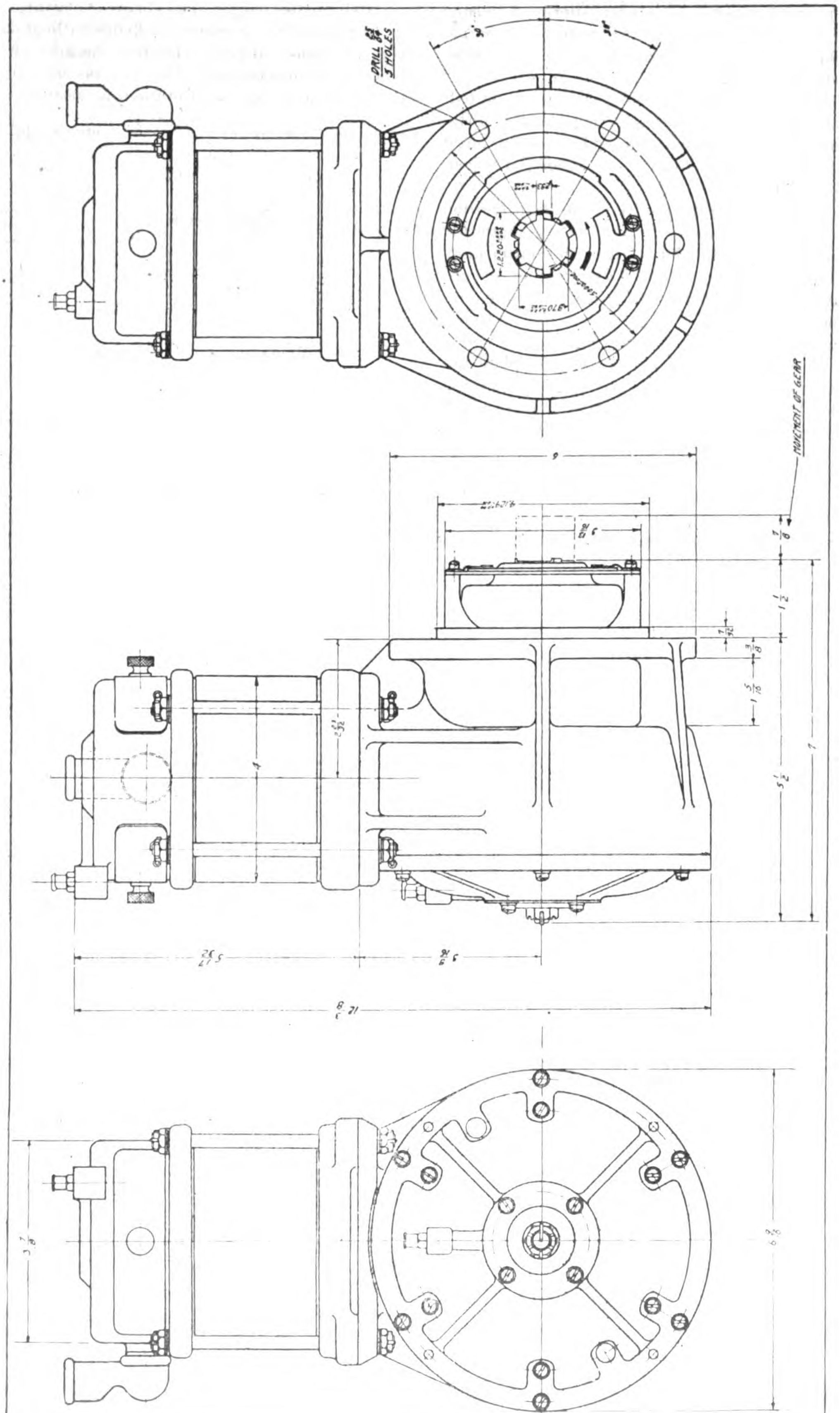


FIG. 1.—Rear end starter for Liberty "12."

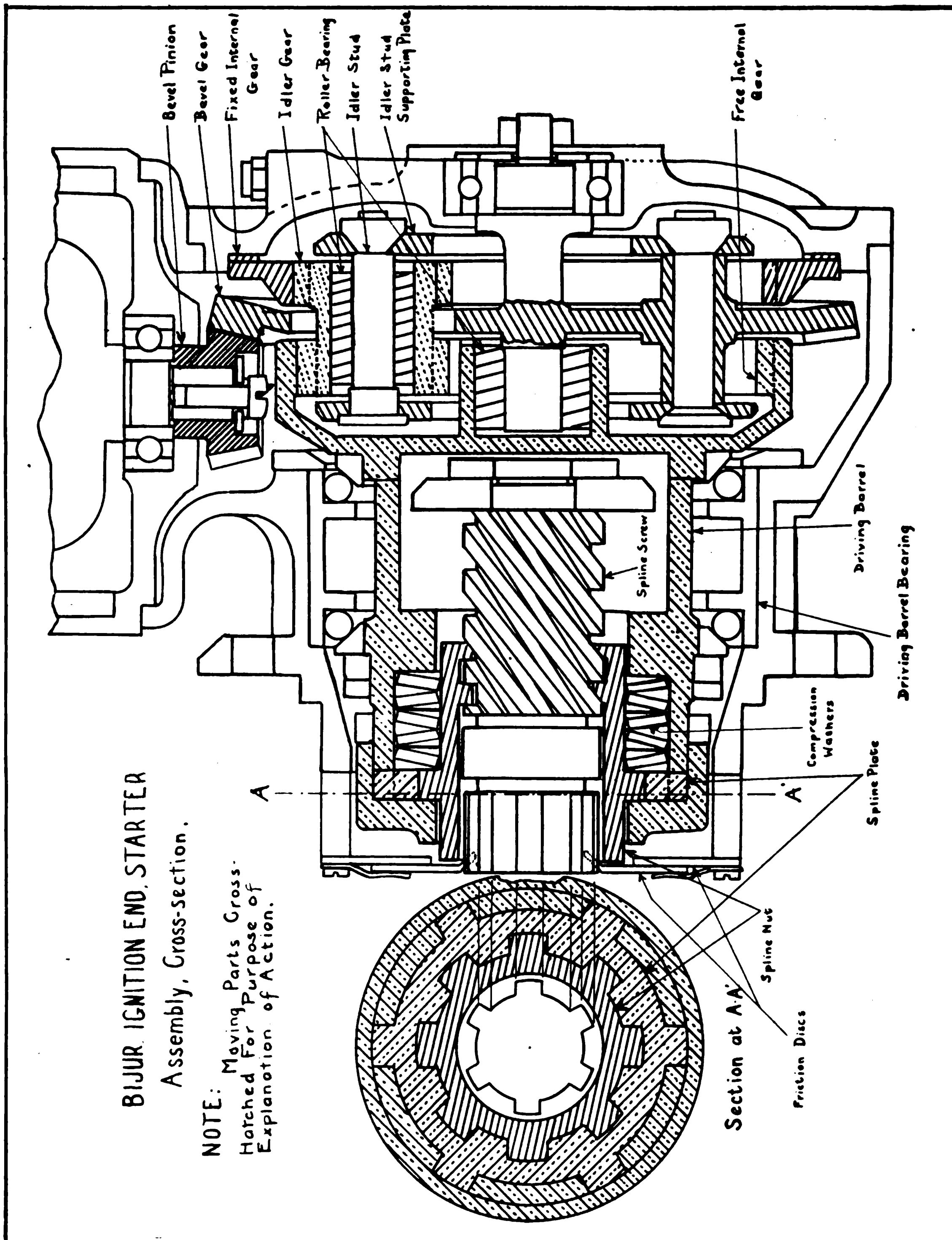

BIJUR IGNITION END STARTER
Assembly, Cross-section.
NOTE: Moving Parts Cross-Hatched For Purpose of Explanation of Action.
Bevel Pinion
Bevel Gear
Fixed Internal Gear
Idler Gear
Roller Bearing
Idler Stud
Idler Stud Supporting Plate
Free Internal Gear
Driving Barrel
Spline Screw
Driving Barrel Bearing
Compression Washers
Spline Plate
A
A'
Spline Nut
Friction Discs
Section at A-A'

FIG 2.

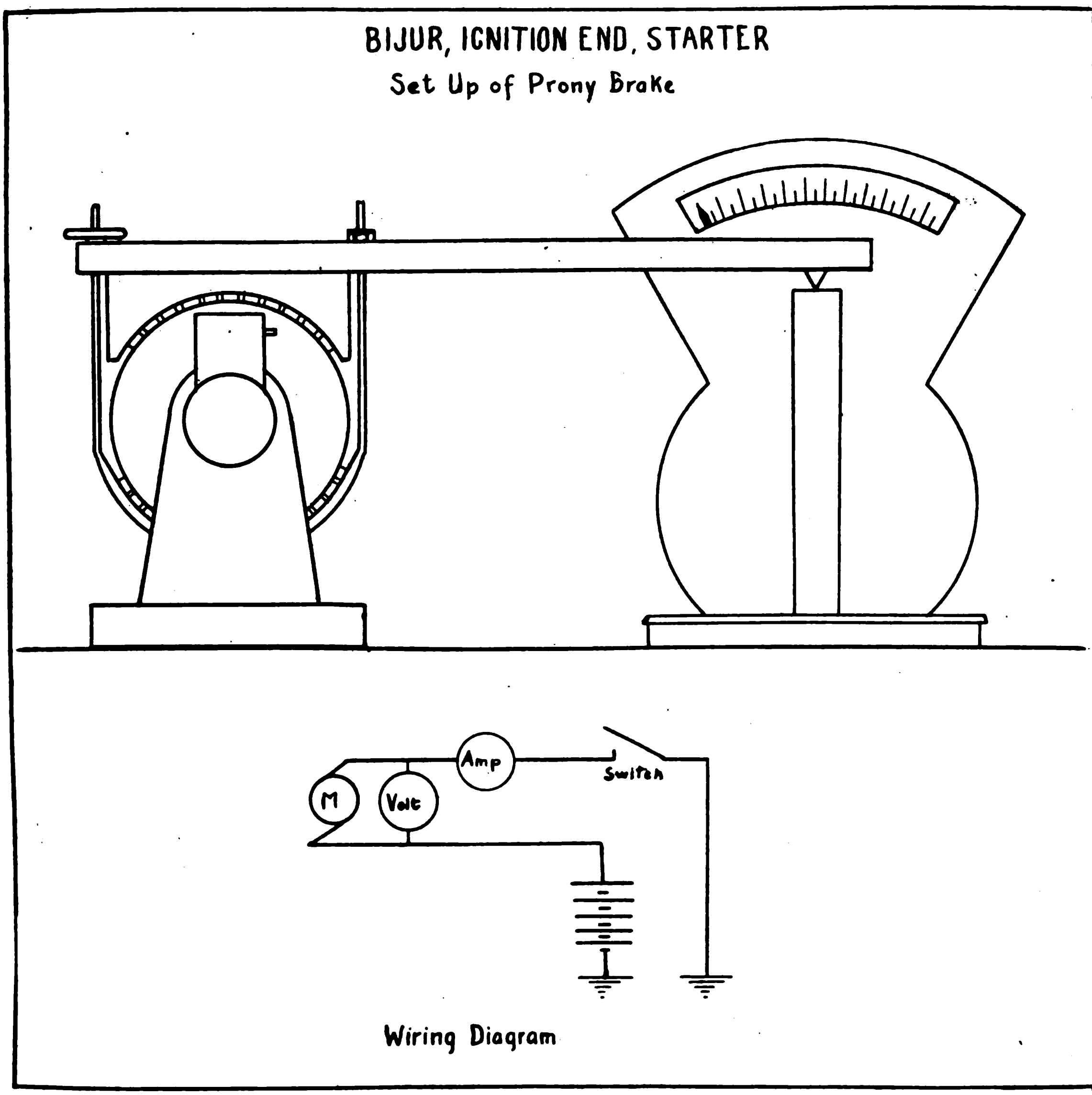
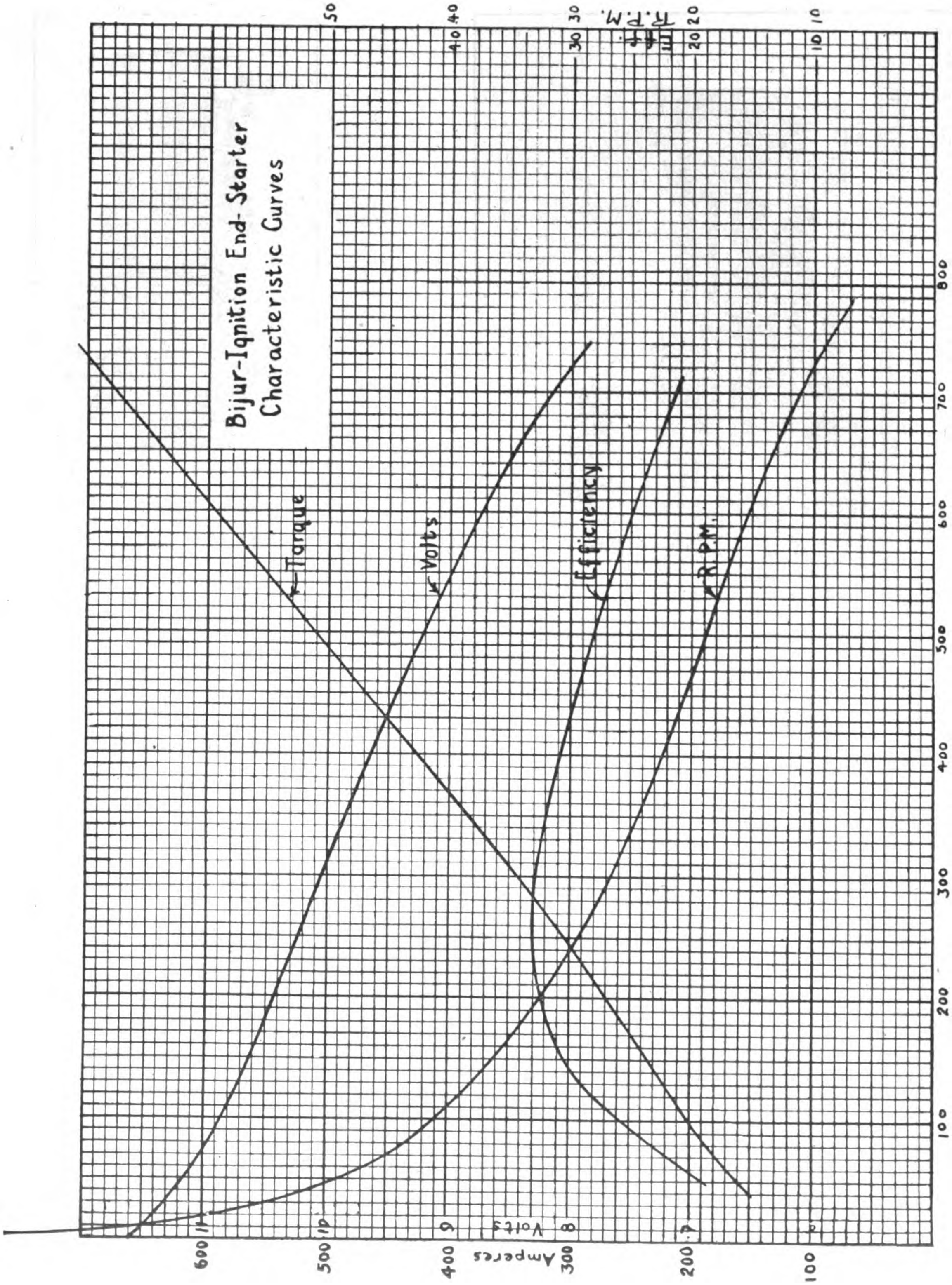

BIJUR, IGNITION END, STARTER
Set Up of Prony Brake
Amp
Switch
M
Volt
Wiring Diagram

FIG. 3.



Bijur-Ignition End-Starter
Characteristic Curves
Torque
Volts
Efficiency
R.P.M.
Amperes
Volts
R.P.M.

FIG. 4.

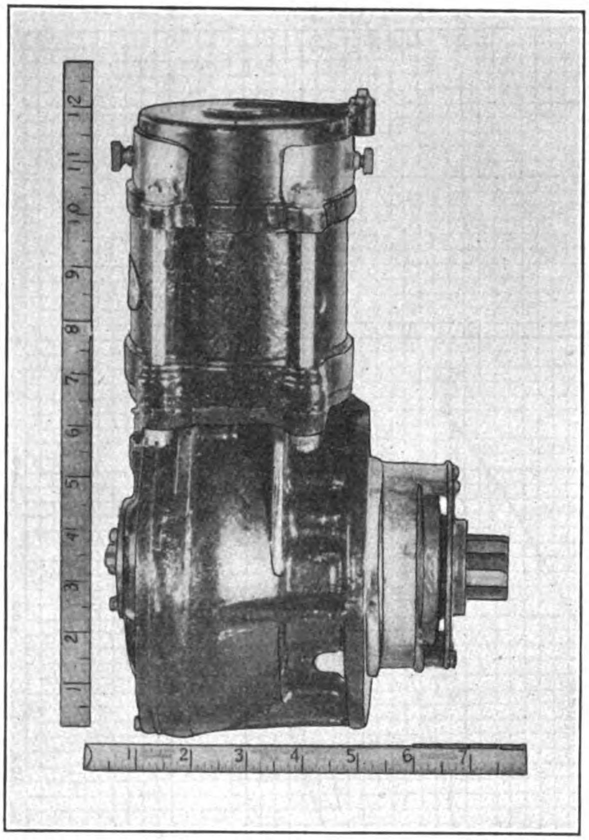


FIG. 5.—Bijur (rear end) starter, side view of assembly.

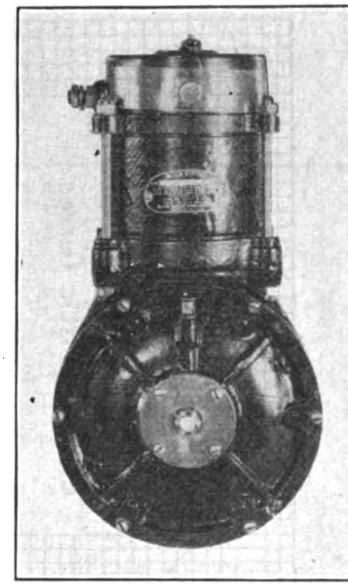


FIG. 6.—Bijur (rear end) starter, front view of assembly.

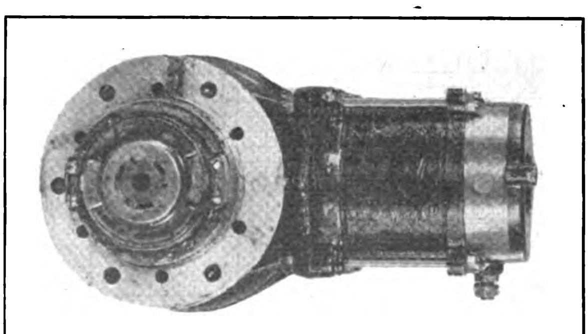


FIG. 7.—Bijur (rear end) starter, rear view of assembly

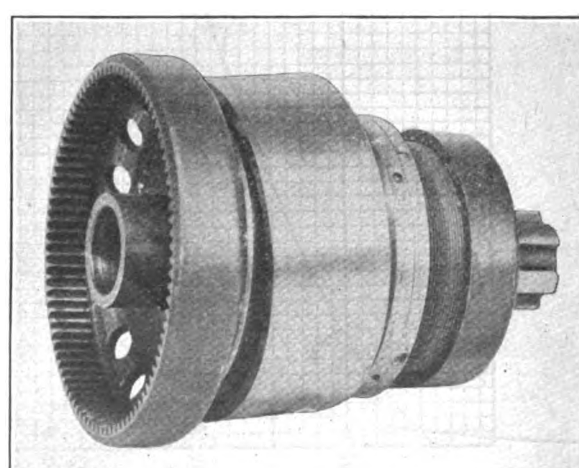


FIG. 8.—Bijur (rear end) starter driving barrel assembly, showing internal gear.

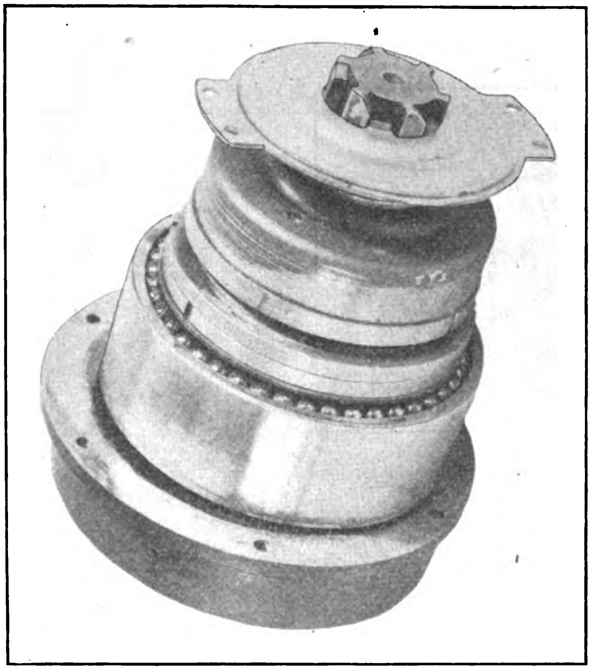


Fig. 9.—Bijur (rear end) starter driving barrel assembly mounted in roller bearing. Also friction discs.

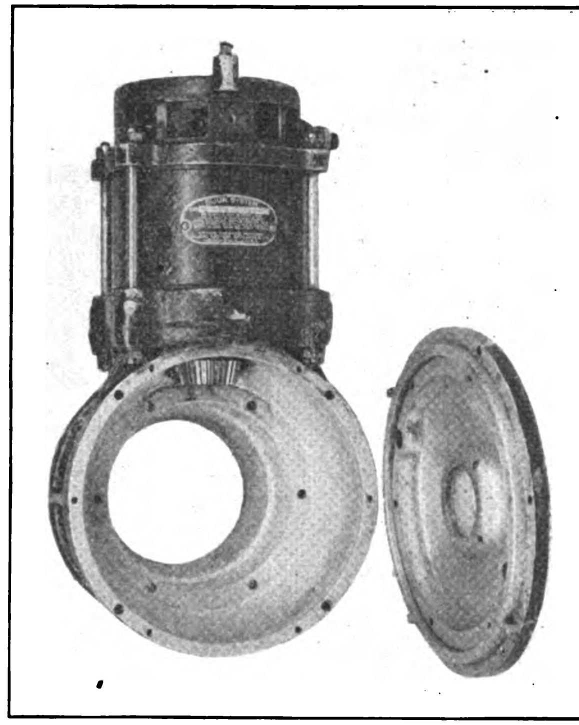


Fig. 10.—Bijur (rear end) starter, showing motor pinion and gear housing.

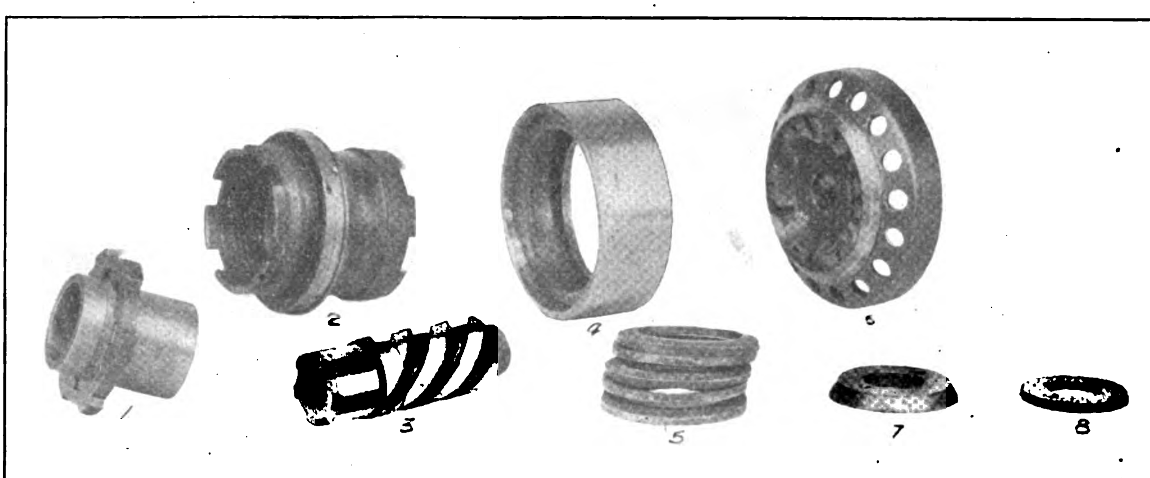


Fig. 11.—Bijur (rear end) starter driving barrel, overload release and automatic engaging device parts.

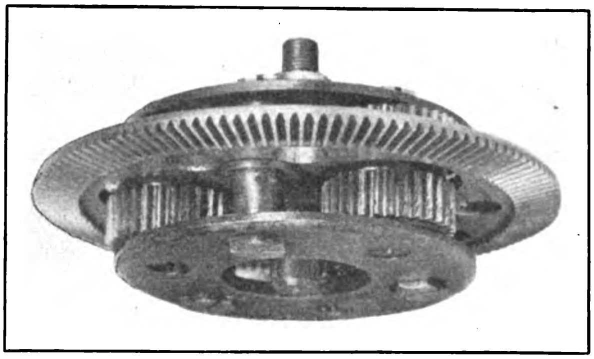


FIG. 12.—Bijur (rear end) starter bevel and idler gear assembly.

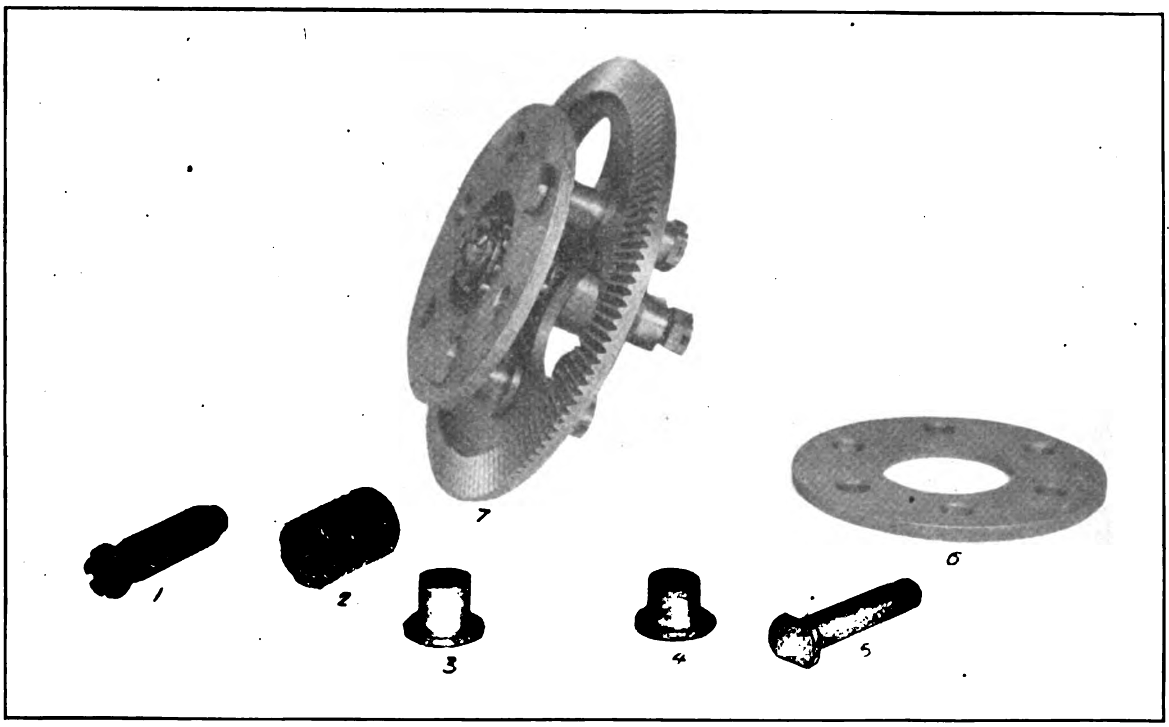


FIG. 13. -Bijur (rear end) starter, bevel and idler gear parts.

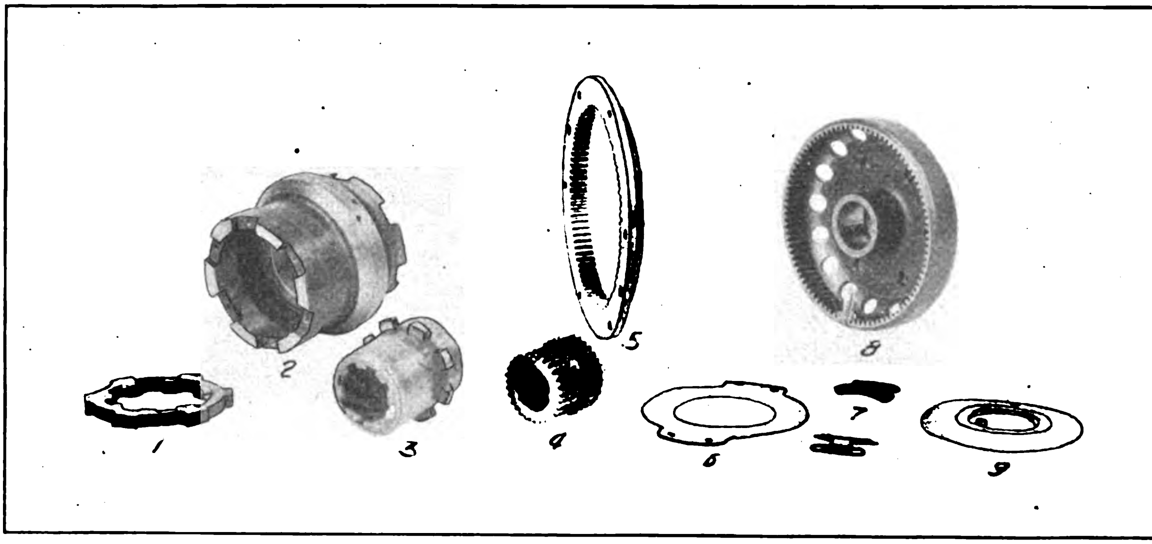


FIG. 14.—Bijur (rear end) starter parts.

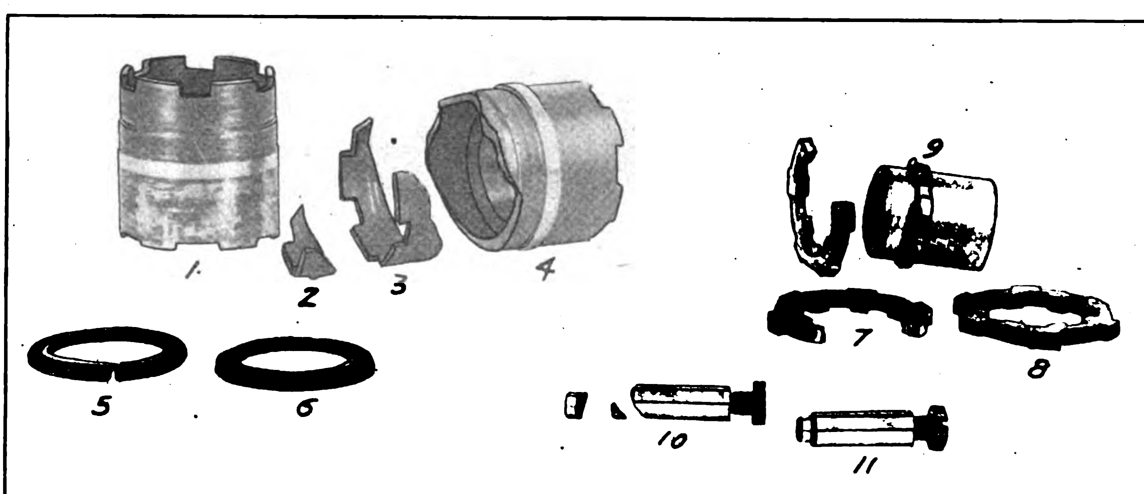


FIG. 15.—Bijur (rear end) starter, showing failure of several parts.

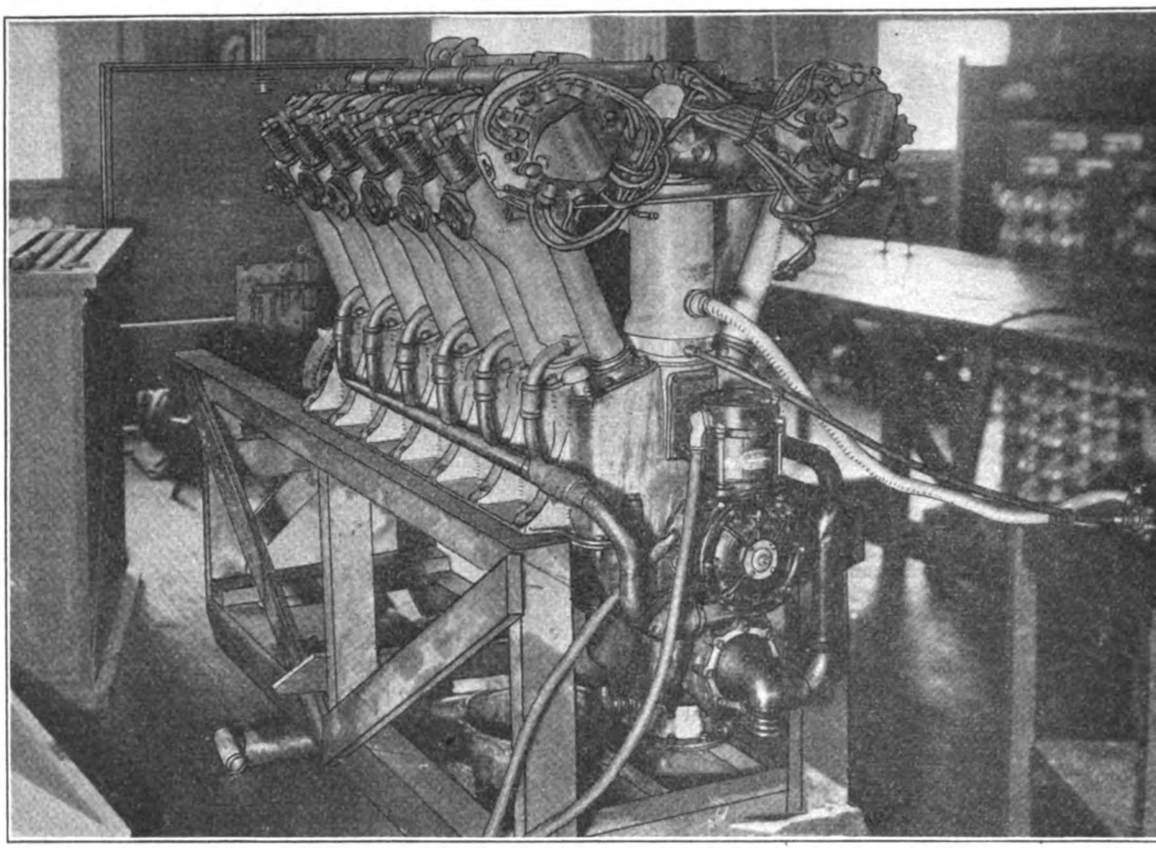


FIG. 16.—Bijur (rear end) starter installed.

~~CONFIDENTIAL~~
File D 52.1/Loening/12

McCOOK FIELD REPORT, SERIAL No. 1902

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV	July 1, 1922	No. 358

STATIC TEST OF THE LOENING PA-1 SINGLE-SEATER PURSUIT AIRPLANE

(AIRPLANE SECTION, S. & A. BRANCH)

Prepared by
D. B. Weaver
Engineering Division, Air Service
McCook Field, Dayton, Ohio
April 10, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

STATIC TEST OF THE LOENING PA-1 SINGLE-SEATER PURSUIT PLANE.

SUMMARY OF RESULTS.

Airplane: Loening PA-1; A. S. No. 64247.
Type: III.
Total weight: 2,461 pounds.
Wing cellule weight: 309 pounds.
Wing area: 282.5 square feet.
Engine: Wright Radial, 350 horsepower.

Description: The Loening PA-1 is a single-seater pursuit biplane. The U. S. A.-27 aerofoil is used. Estimated maximum speed at ground, 140 miles per hour. Wings are constructed of wood and fabric, the fuselage of steel tube with wire bracing. Built by the Loening Aeronautical Engineering Corporation, New York.

RESULTS OF TEST.

Date.	Part tested.	Load required.	Pounds per square foot or factor supported.	Failed at.	Weight.	Failure.
Sept. 26, 1921	Horizontal stabilizer.	35 pounds per sq. ft.	50 pounds per sq. ft.	....	0.94 pounds per sq. ft.	
Do	Elevator	do	41.5 pounds per sq. ft.	50 pounds per sq. ft.	0.75 pounds per sq. ft.	First diagonal rib outward from the control mast failed in bending.
Do	Elevator control	do	do	No failure	....	Held satisfactorily.
	Vertical fin	....	....	....	....	
Sept. 27, 1921	Rudder	30 pounds per sq. ft.	45 pounds per sq. ft.	47.5 pounds per sq. ft.	1.02 pounds per sq. ft.	Ribs failed in bending.
Do	Rudder control	do	do	No failure	....	
Oct. 1, 1921	Ailerons	35 pounds per sq. ft.	35 pounds per sq. ft.	do	0.76 pound per sq. ft.	Not carried to destruction.
Do	Aileron control wing cellule.	do	15 pounds per sq. ft.	20 pounds per sq. ft.	....	Pulley bracket tore loose from wing spar.
Oct. 5, 1921	High incidence	Factor 8.5	Factor 9	No failure	....	Wing held satisfactorily, but the fuselage longerons began to buckle at the points of support.
Oct. 4, 1921	Low incidence	Factor 5.5	Factor 5.5	do	....	
Sept. 30, 1921	Reverse load	Factor 3.5	Factor 3.79	do	....	
Oct. 12, 1921	Six foot length of leading edge.	Factor 14	....	Factor 16.6	....	
Oct. 10, 1921	Fuselage	Factor 7	Factor 7	Factor 7.5	Bare 92.5 pounds.	Wire broke in second to last bay, left side, after holding 7.5 for 3 minutes.
	Tail skid	....	....	....	....	
Oct. 4, 1921	Chassis:					
	Struts	6	7	No failure	....	Axle showed a permanent set at a factor of 6.5.
	Axle	5-5.5	6	6.5	....	
	Shock absorber.	5	Fully extended at 7.			

Discussion.—Redesign aileron pulley bracket. Change method of attaching aileron pulley bracket to spar to prevent splitting of the spar. Redesign rib where aileron pulley bracket is attached.

OBJECT.

This static test was conducted for the purpose of determining the structural strength of the Loening PA-1 airplane submitted in accordance with contract No. 357, dated January 20, 1921.

DATE AND PLACE.

Dates tested.	Parts tested.
Sept. 26, 1921	Elevator and stabilizer.
Sept. 27, 1921	Rudder.
Oct. 1, 1921	Ailerons.
Sept. 30, 1921	Wing cellule (reversed flight).
Oct. 4, 1921	Wing cellule (low incidence).
Oct. 5, 1921	Wing cellule (high incidence).
Oct. 12, 1921	Leading edge.
Oct. 12, 1921	Fuselage.
Oct. 10, 1921	Chassis.

These tests were conducted at McCook Field, Dayton, Ohio.

WITNESSES.

Lieut. E. W. Dichman... All tests.
Lieut. C. W. Pyle........ All tests.
Lieut. C. N. Monteith.... Not present at empennage tests.
W. E. Savage............. All tests.
D. B. Weaver............. All tests.

GENERAL RECOMMENDATIONS.

Wing cellule—None.

Aileron—Redesign the lower rear spars, the aileron control cable pulley bracket, and replace the compression rib.

Empennage—None.

Fuselage—None.

Landing chassis—None.

GENERAL DESCRIPTION.

The Loening PA-1 is a single seater pursuit biplane, propelled by a 350-horsepower 9-cylinder air-cooled fixed radial Wright engine.

The estimated performance from tests on a wind tunnel model is 140 miles per hour at sea level.

Total weight	2,461 pounds.
Disposable load	922 pounds.
Total wing area	282.5 square feet.
Weight per square foot of lifting surface	8.7 pounds.
Weight per horsepower	7.04 pounds.
Aerofoil	U. S. A.-27.

For front and side elevations, see Figure 1. For plan view, see Figure 2.

Figures 3 and 4 are photographs of the assembled airplane before it was static tested.

The list of armament and equipment is according to Air Service Specification No. 1,518-C.

This airplane was built by the Loening Aeronautical Engineering Corporation of New York City.

WING CELLULE.

DESCRIPTION.

The wing cellule consists of an upper and lower wing with an N-type interplane strut on each side. The flying wires are double and the landing wires are single.

Wing.	Area.
Upper	144.5 square feet.
Lower	138 square feet.

Figures 5 and 6 are assemblies of the upper and lower wing. They are built upon two routed spruce spars to which the type of rib shown in Figure 7 is attached. Cross sections of the wing spars are shown in Figure 8. The wing tips are made from one piece of balsa wood having a semicircular cross section with an outside radius at any point equal to one-half the aerofoil thickness.

The leading edge is covered with three-ply gum plywood and the wings completely covered with cotton fabric.

The interplane struts are made of mild steel tubing welded at the intersections, with balsa wood fairing, cemented and taped to the tube. Figure 9 is an assembly of the end strut.

The ailerons are on the lower wing only. Their movement is controlled by means of a flexible steel cable.

The wing cellule has a structural weight of 1.095 pounds per square foot.

PROCEDURE FOR TEST (REVERSE FLIGHT).

The airplane was assembled as for flight, so that the mean chord made an angle of 14 degrees with the horizontal, trailing edge down.

The center of gravity of the load was located at 25 per cent of the chord from the leading edge of the wing.

The load was applied according to the loading schedule (Fig. 10). After a load had been put on and supported for five minutes, deflection readings at 10 points along the spar were taken and the retreat of the wing tips measured as indicated in Figure 11.

RESULTS.

The wing supported the required factor of 3.5 satisfactorily. The bearing surface of the clip which connects the spar to the fuselage had crushed into the spar one-sixteenth of an inch. For tabulated results and spar deflection curves, see Figures 11 and 12.

PROCEDURE FOR TEST (LOW INCIDENCE).

The airplane was set up in an inverted position so that the angle r between the wing chord and the horizontal was 14° 10′, trailing edge down.

The angle of incidence α, of the wing at low incidence, and B the angle between the vertical and resultant air force, are determined from wind-tunnel data.

$$\angle\alpha=-2°-48'.$$
$$\angle\beta=\cot^{-1} L/D=\cot^{-1} 4.97=11°-22'.$$
$$\angle\gamma=\angle\beta-\angle\alpha=(11°-22')-(-2°-48')=14°-10'.$$

The center of pressure at a value of $\angle\alpha=-(2°-40')$ is 60 per cent of the chord from the leading edge. The center of gravity of the load was located the same distance from the leading edge of the wing as the center of pressure.

The load was applied according to the loading schedule, Figure 13. At the points indicated in Figure 14, deflection and retreat readings were taken after each load increment had been supported for five minutes.

RESULTS.

Figures 14 and 15 give the spar deflections and wing tip retreat in tabulated form.

The required load factor of 5.5 was supported without failure.

PROCEDURE FOR TEST (HIGH INCIDENCE).

The airplane was reset so that the angle between the wing chord and horizontal represented by γ, was 10°-10′ leading edge down.

$$\alpha=17°-12'$$
$$\beta=\cot^{-1} L/D=\cot^{-1} 8.1=7°-2'$$
$$\gamma=\alpha-\beta=17°-12'-7°-2'=10°-10'.$$

The center of gravity of the load was located at 29 per cent of the wing chord.

The loads were placed according to the loading schedule, Figure 16. Deflection and retreat readings were taken at points indicated in Figure 17, after each load increment had been supported for five minutes.

RESULTS.

Deflections of the wing spars and wing tip retreat are given in tabulated form, Figure 17. Figure 18 gives the wing spar deflection curves.

At a required factor of 8.5 the longerons began to bend at the point where the fuselage was supported.

At a factor of 9, the wings held the load satisfactorily, but the test was discontinued due to the weakness of the fuselage.

DISCUSSION.

The results of the tests made by the Material Section on the wing spars are as follows:

> The moisture content of the spars was uniform and approximately what might be expected for the time of year.
>
> The specific gravity of all the spars was above the minimum requirement of Air Service Specifications.

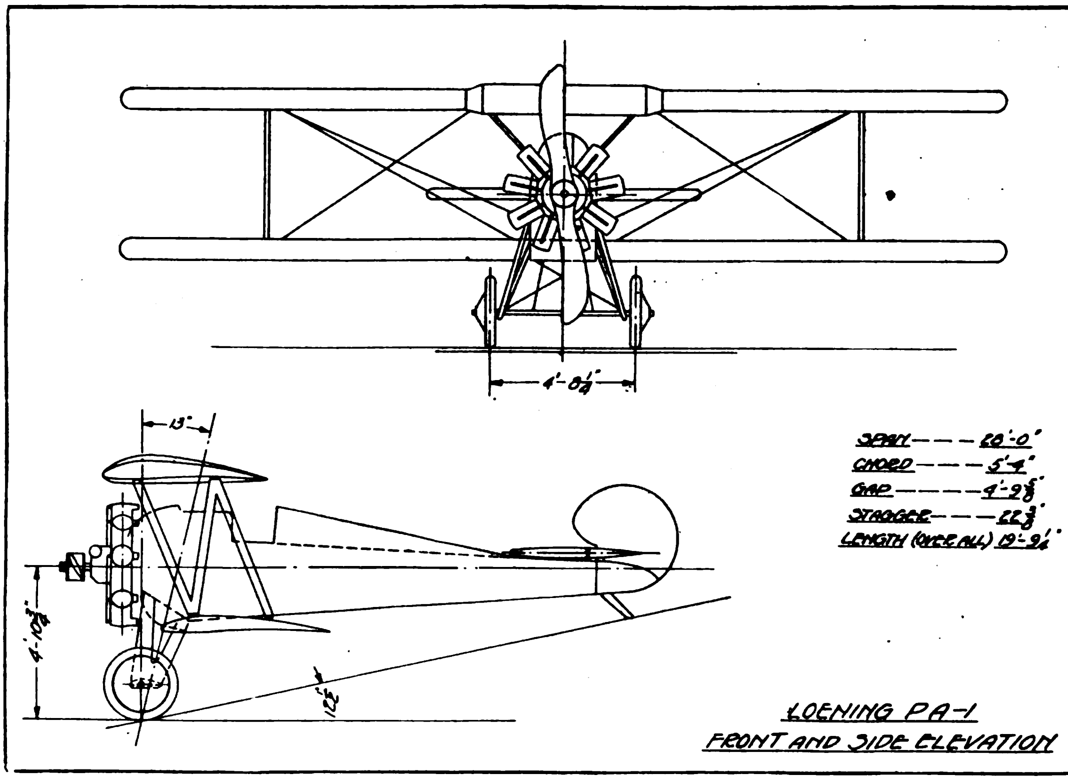


FIG. 1.

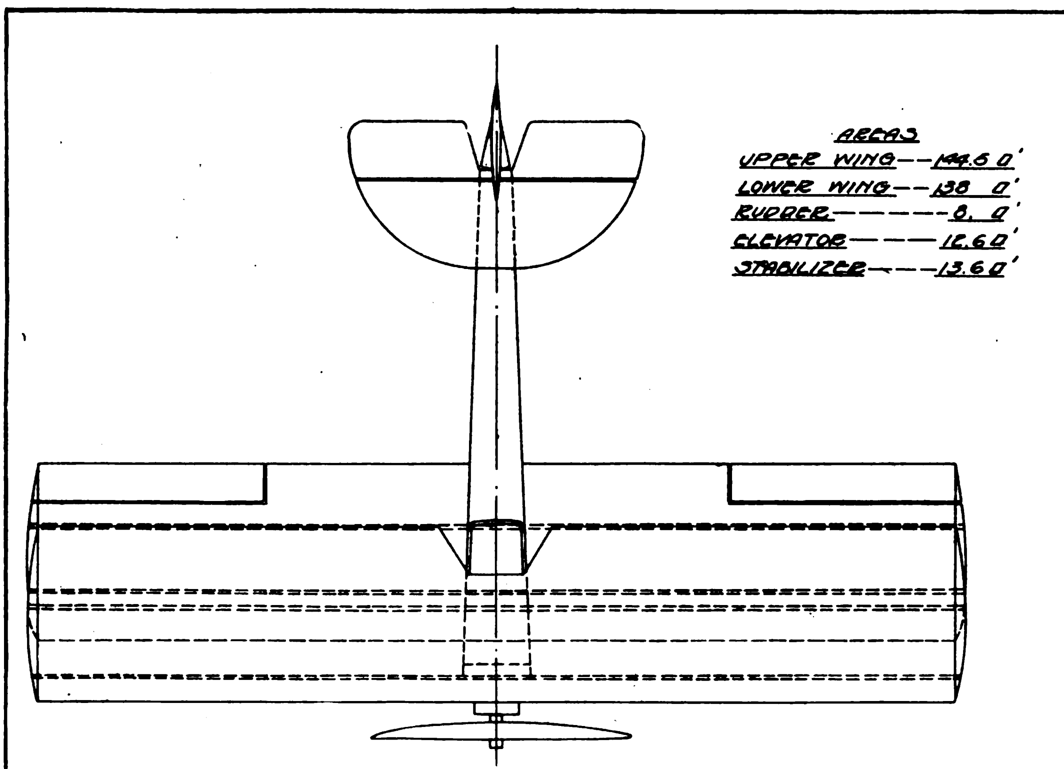


FIG. 2.—Loening PA-1, Wright Radial, 340 horsepower.

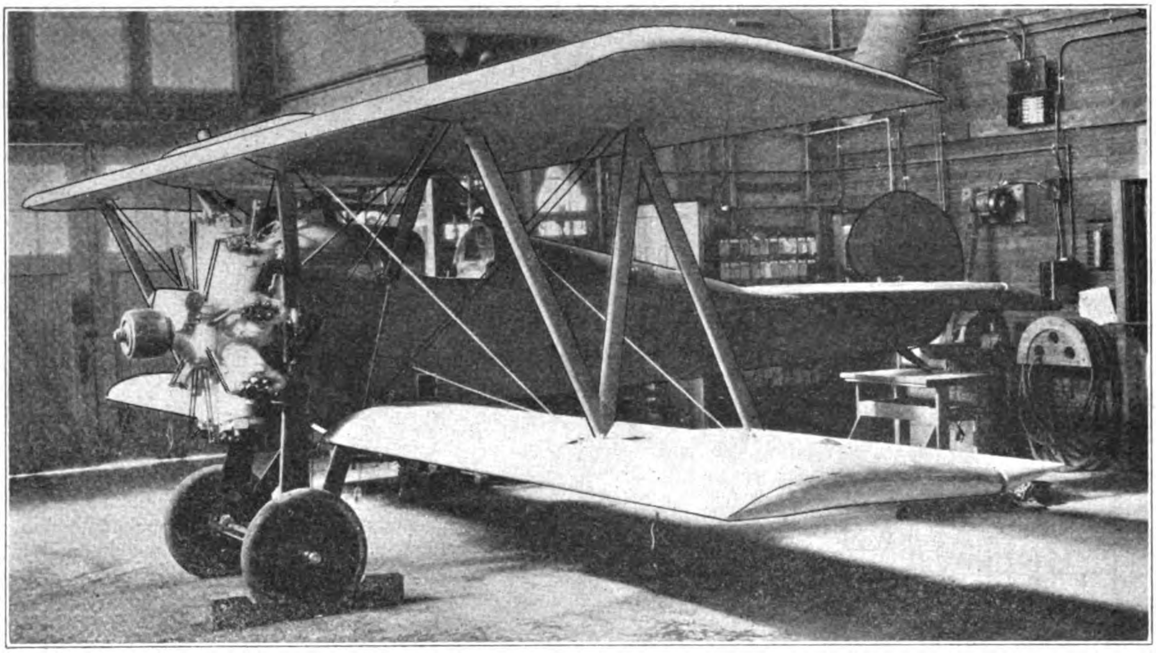


FIG. 3.

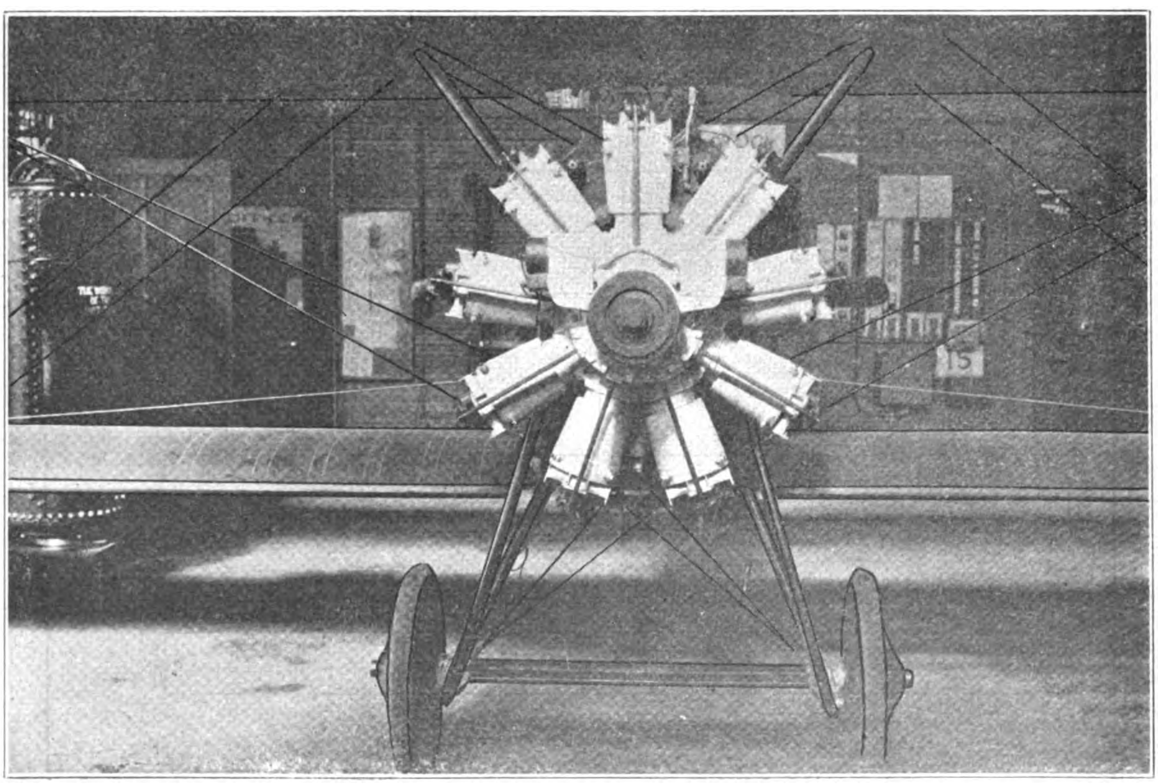


FIG. 4.

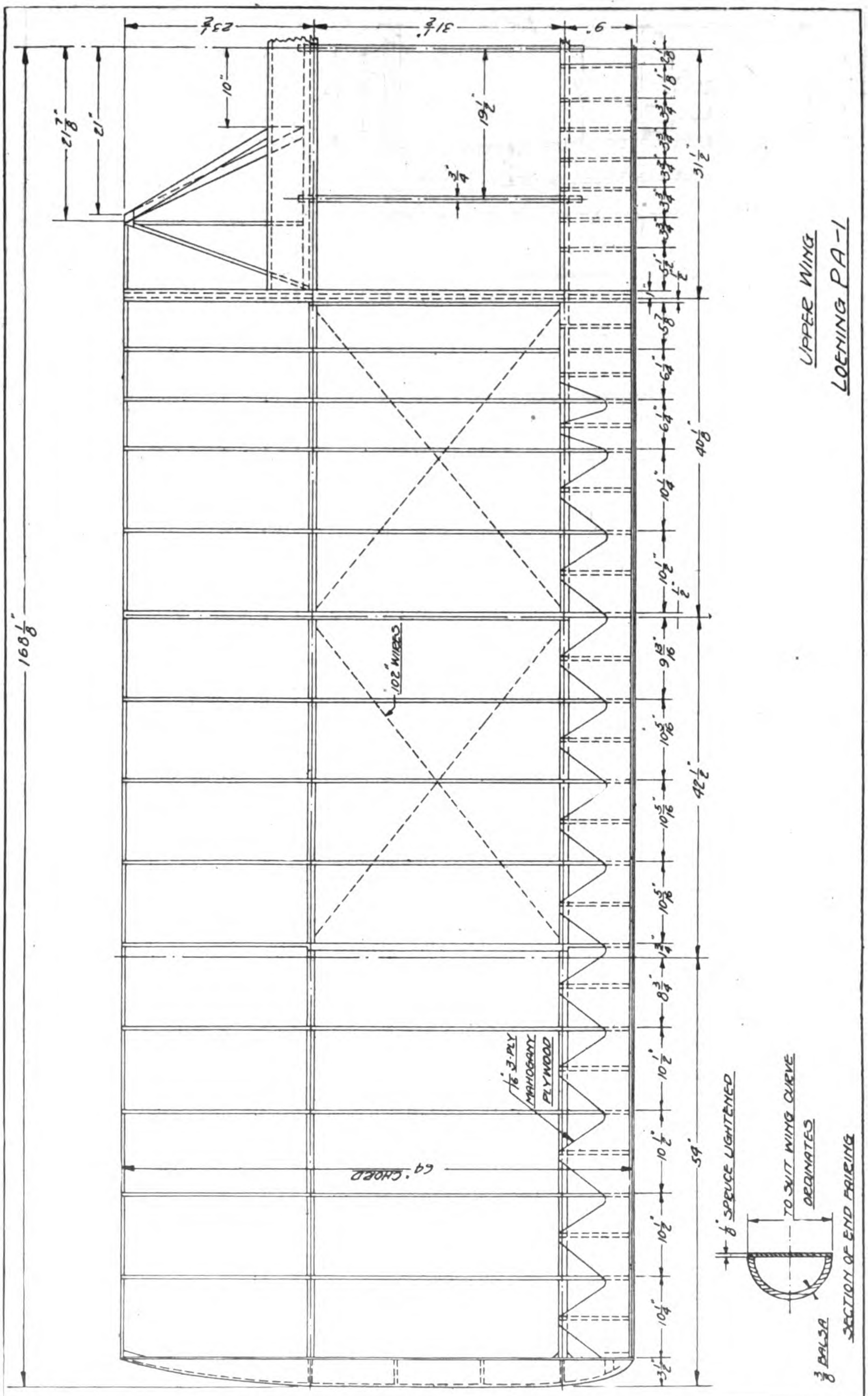

UPPER WING
LOENING PA-1
102" WIRES
1/16" 3-PLY
MAHOGANY
PLYWOOD
69" CHORD
1/8" SPRUCE LIGHTENED
TO SUIT WING CURVE
ORDINATES
3/8 BALSA
SECTION OF END FAIRING
168 1/8"
21 7/8"
21"
10"
19 1/2"
31 1/2"
40 1/8"
42 1/2"
59"
23 7/8
31 1/2
9

FIG. 5.

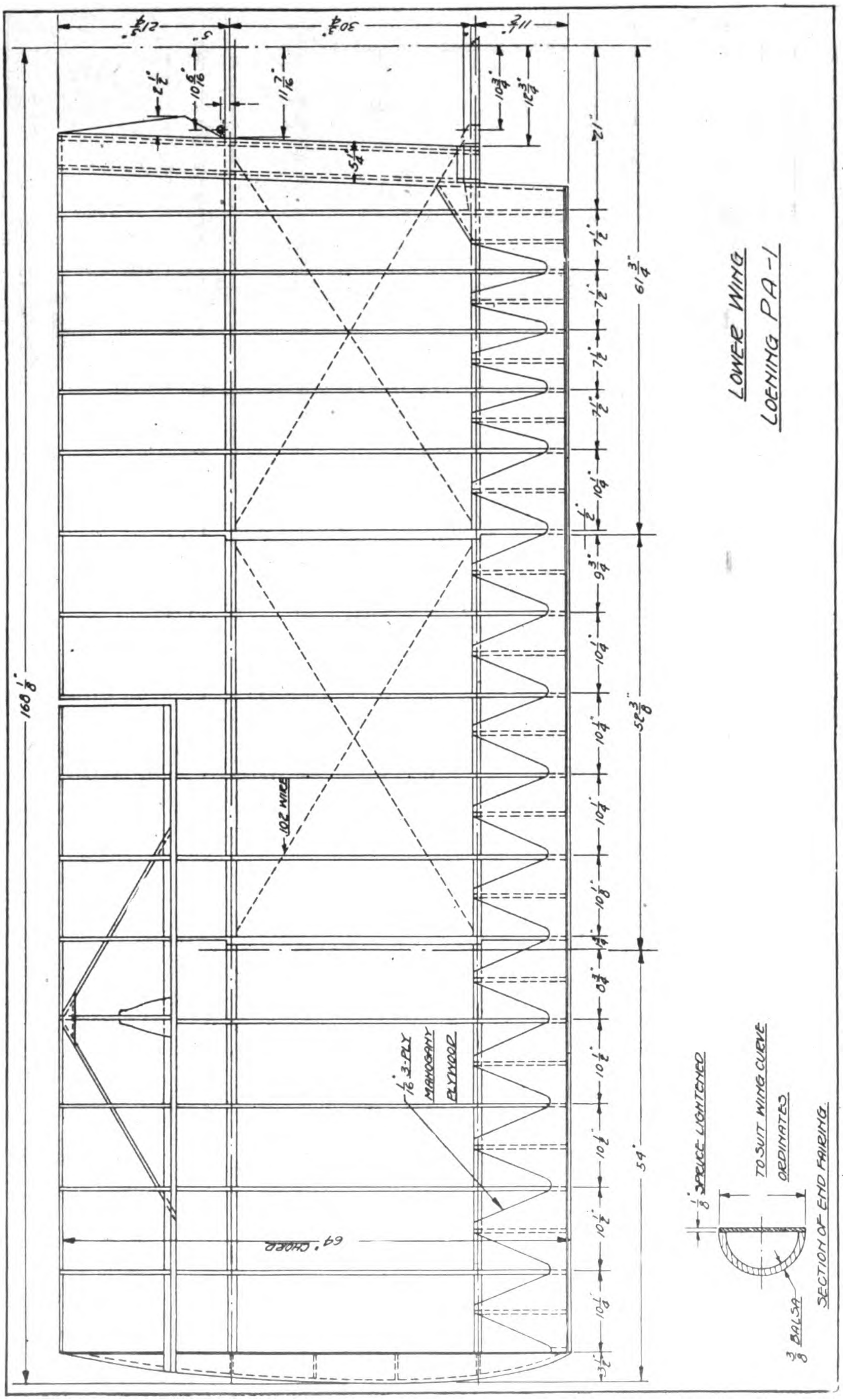

LOWER WING
LOENING PA-1
1/16" 3-PLY MAHOGANY PLYWOOD
10Z WIRE
69" CHORD
1/8" SPRUCE LIGHTENED
TO SUIT WING CURVE ORDINATES
3/8 BALSA
SECTION OF END FAIRING
168 1/8"
61 3/4"
52 3/8"
54"

Fig. 6.

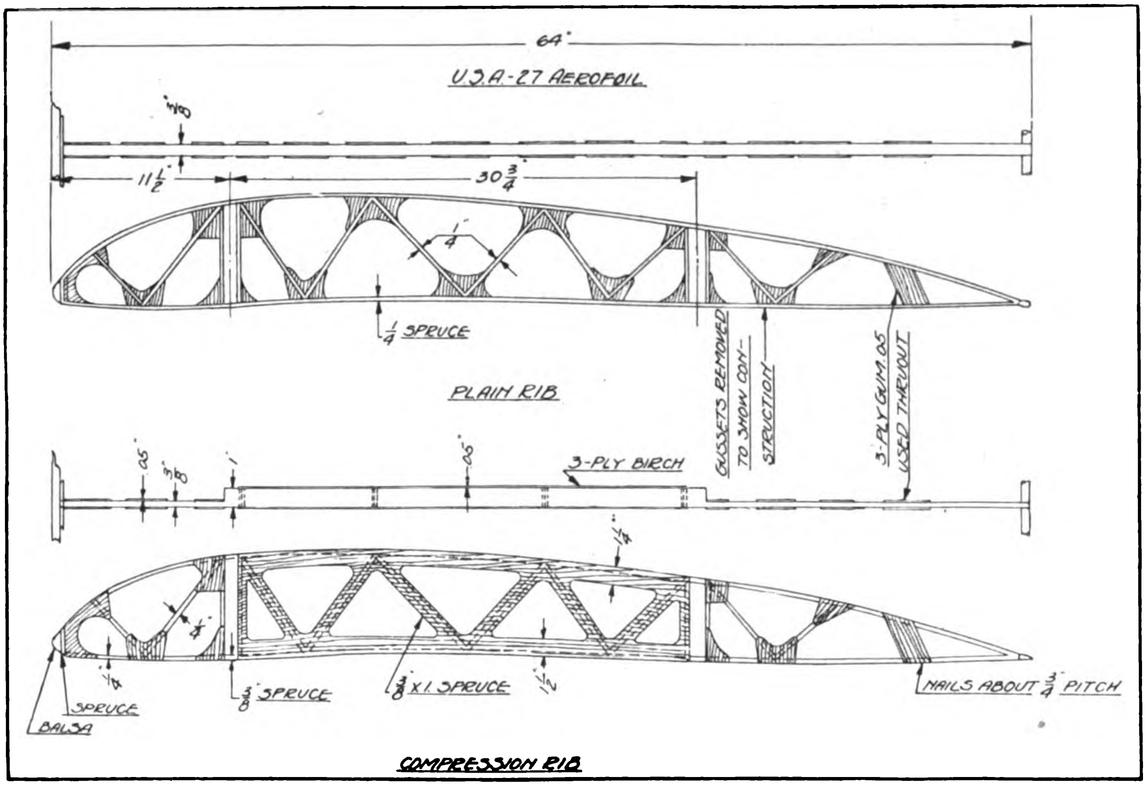


Fig. 7.—Typical wing ribs of the Loening PA-1.

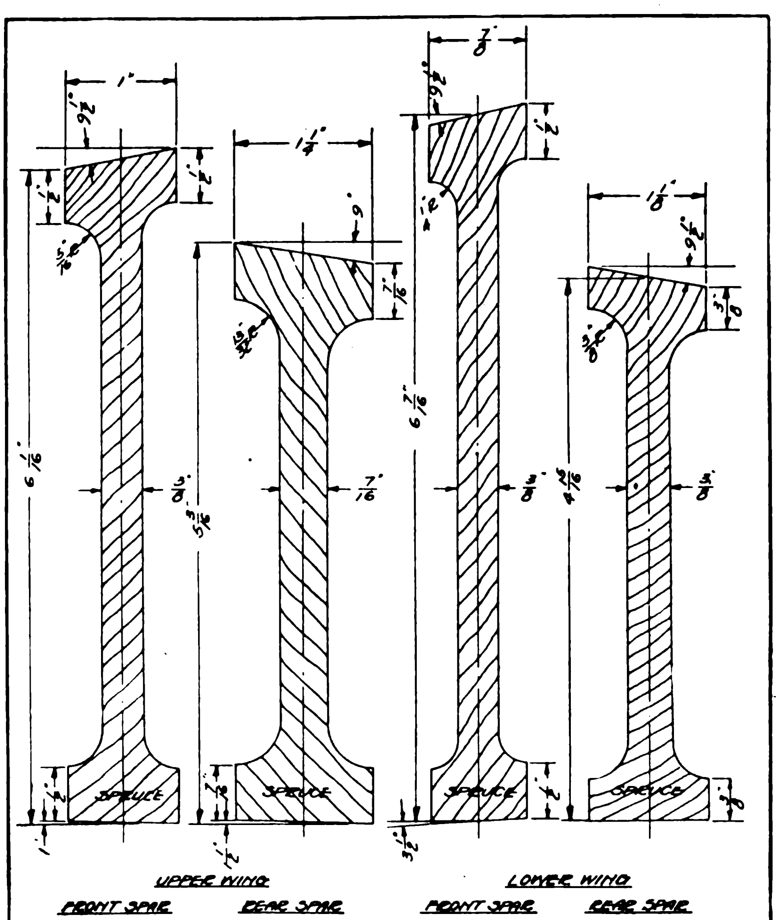


Fig. 8. Spar sections of the Loening PA-1.

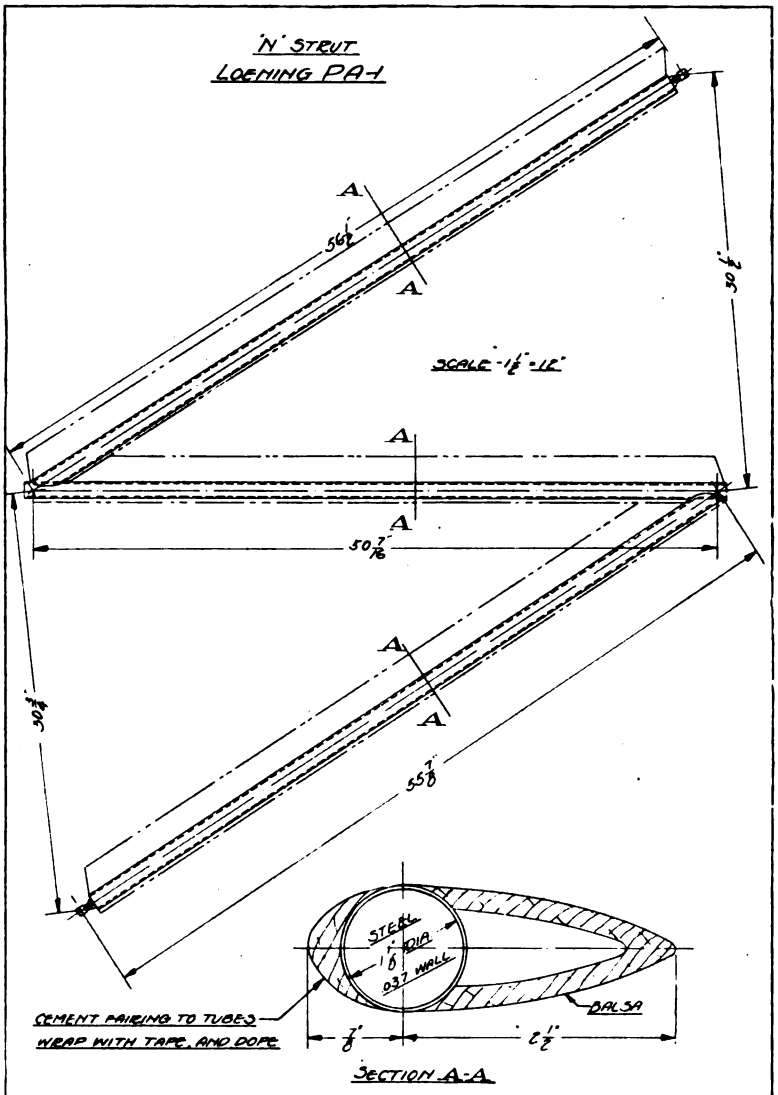
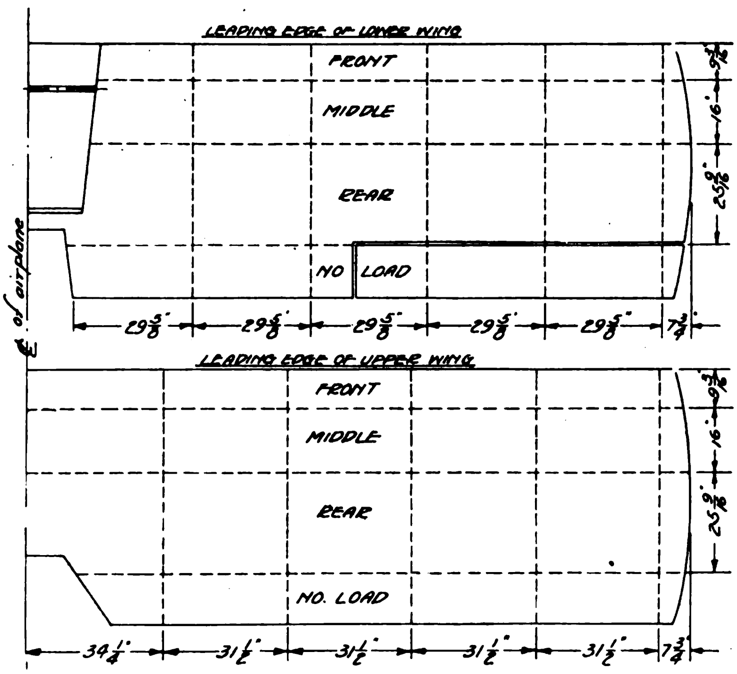
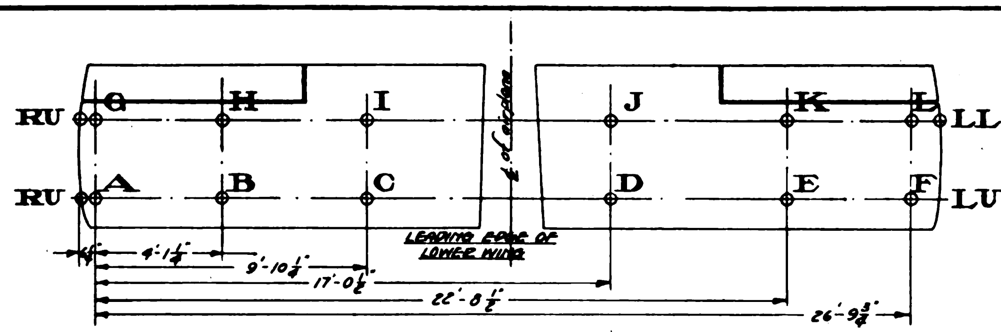

'N' STRUT
LOENING PA-1
A
A
56½"
30¾"
SCALE - 1½" = 12"
A
A
50 7/16"
A
A
30¾"
55⅞"
STEEL
1⅛" DIA
.037 WALL
BALSA
CEMENT FAIRING TO TUBES
WRAP WITH TAPE, AND DOPE
⅞"
2½"
SECTION A-A

FIG. 9.



LOAD FACTOR	UPPER WING			TOTAL LOAD IN POUNDS	LOWER WING			TOTAL LOAD IN POUNDS
	F	M	R		F	M	R	
1.90	97	48	48	1930	93	46	46	1850
2.37	26	13	13	2450	25	13	12	2350
2.84	″	″	″	2970	″	″	″	2850
3.32	″	″	″	3490	″	″	″	2350
3.79	″	″	″	4010	″	″	″	3850

FIG. 10.—Loading schedule for the reverse load static test of the Loening PA-1.



LOAD FACTOR	DEFLECTION IN INCHES												RETREAT			
	A	B	C	D	E	F	G	H	I	J	K	L	LL	LU	RL	RU
1.90	.8	.8	.4	.3	.2	.3	.1	.1	-.2	.3	.5	.8	+.3	.0	-.4	-.4
2.37	1.2	1.1	.5	3	.4	.4	2	.1	-.2	.4	.7	1.2	+.3	.0	-.5	-.6
2.84	1.3	1.3	.7	.4	.3	.4	.1	.2	-.1	.6	.9	1.4	+3	.0	-.4	-.7
3.32	2.0	1.6	.9	.4	.2	.4	.0	.1	-.1	.7	1.2	1.8	+.3	.0	-.6	-.9
3.79	2.4	1.7	1.0	.4	.3	.5	.2	.1	-.1	.7	1.4	2.1	+.3	.1	-.6	-1.0

FIG. 11.—Tabulated results of the reverse loading static test of the Loening PA-1.

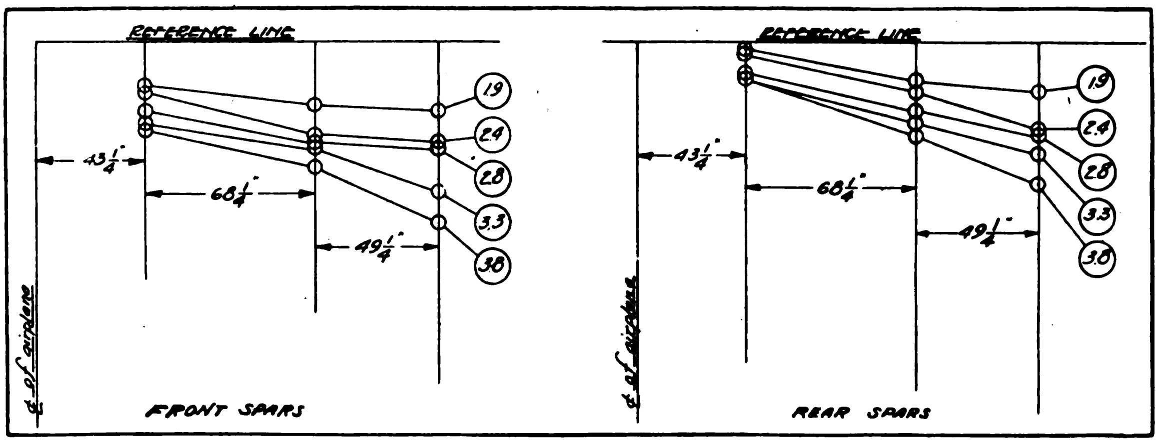
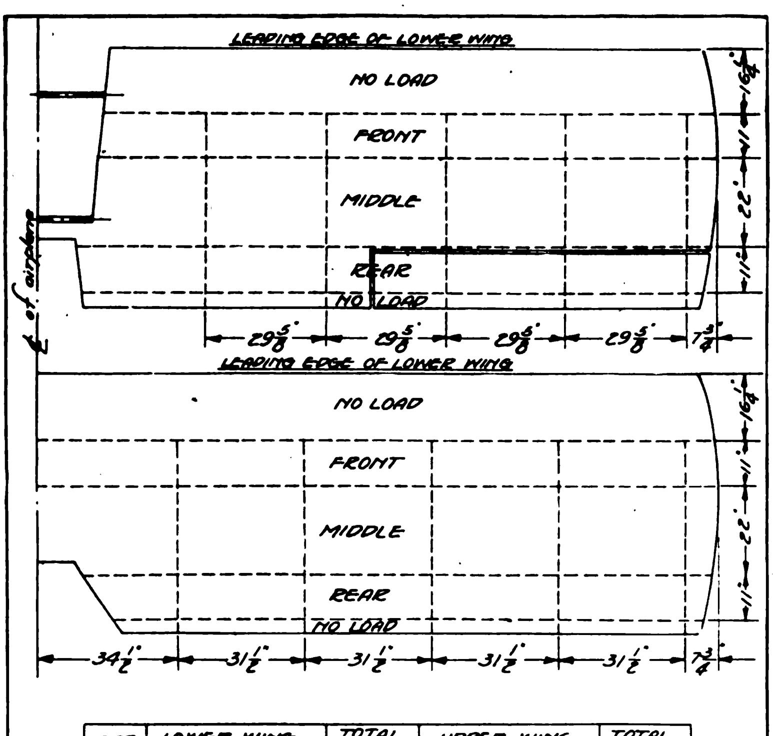
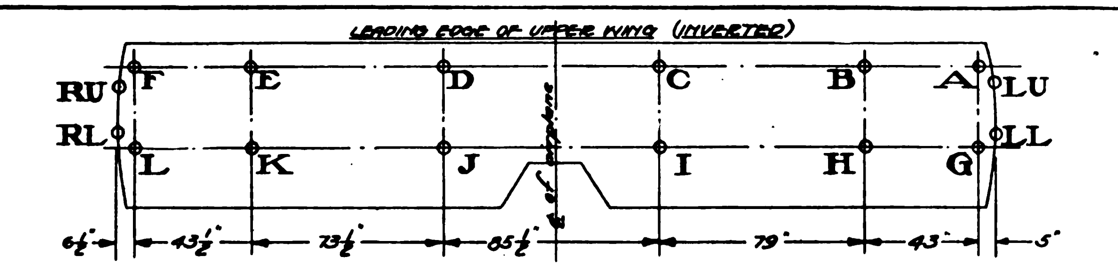


FIG. 12.—Curves showing mean deflection of the wing spars at points indicated during static test for reverse flight condition on the Loening PA-1.



LOAD FACTOR	LOWER WING F	LOWER WING M	LOWER WING R	TOTAL LOAD IN POUNDS	UPPER WING F	UPPER WING M	UPPER WING R	TOTAL LOAD IN POUNDS
3	66	133	66	2640	87	176	87	3500
4	23	47	23	3570	31	61	31	4730
4.5	12	23	12	4040	15	32	15	5350
5.0	"	"	"	4510	"	"	"	5970
5.5	"	"	"	4980	"	"	"	6590

FIG. 13.—Loading schedule for the low angle of incidence static test of the Loening PA-1.



LOAD FACTOR	DEFLECTION IN INCHES												RETREAT			
	A	B	C	D	E	F	G	H	I	J	K	L	LU	LL	RU	RL
3	.4	1.0	.1	.1	.5	.4	1.2	.6	.3	.5	.8	1.2	-.2	+.4	-.2	+.5
4	.5	1.1	.2	.9	.5	.8	1.7	.9	.4	.7	1.2	1.9	-.2	+.6	-.3	+.8
4.5	.6	1.5	.4	.2	.7	.6	2.0	1.1	.4	.7	1.2	2.2	-.4	+.8	-.3	+1.0
5.0	.6	1.3	.3	.5	.7	.7	2.2	1.1	.4	.8	1.6	2.7	-.4	+.9	-.4	+1.2
5.5	.5	1.3	.2	.2	.8	.9	2.5	1.4	.5	.8	1.7	3.0	-.4	+1.0	-.5	+1.4

TEST WAS CONDUCTED WITHOUT ANY FAILURES.

FIG. 14.—Tabulated results of the low angle of incidence static test of the Loening PA-1.

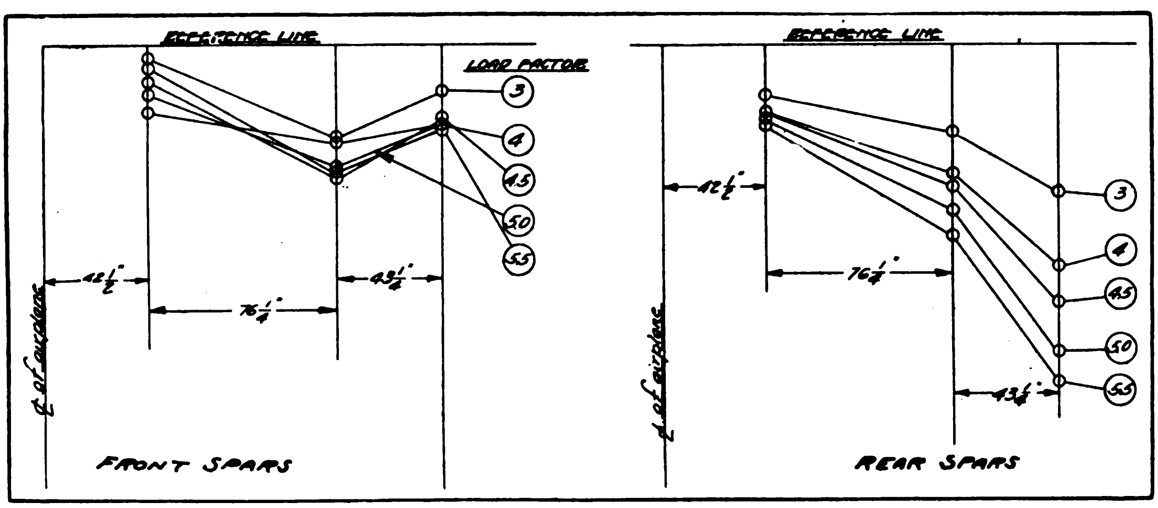
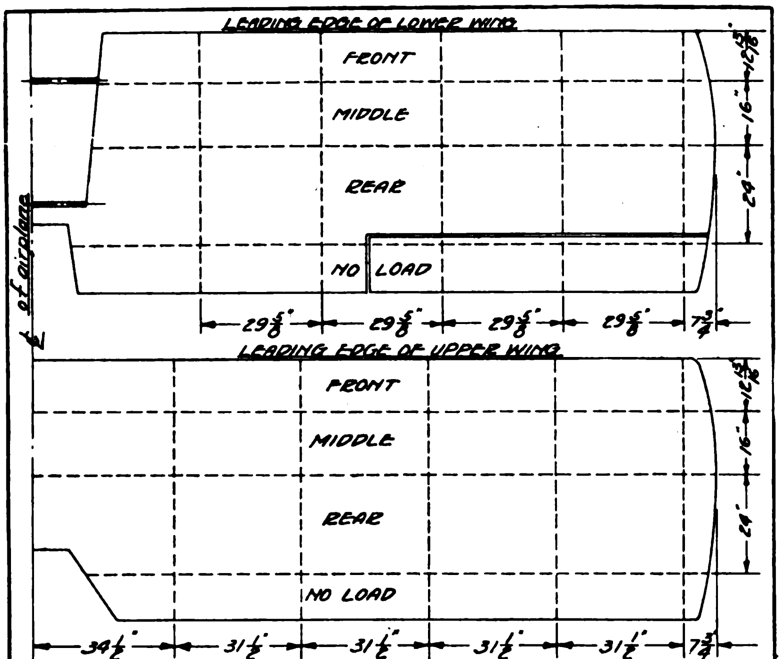
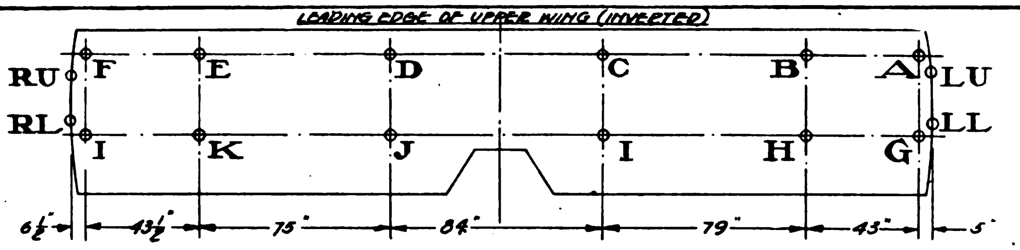


FIG. 15.—Curves showing mean deflection of the wing spars at points indicated during static test for low angle of incidence condition of the Loening PA-1.



LOAD FACTOR	LOWER WING			TOTAL LOAD IN POUNDS	UPPER WING			TOTAL LOAD IN POUNDS
	F	M	R		F	M	R	
3	136	68	68	2710	172	86	86	3490
4	47	24	24	3660	60	31	30	4650
5	"	"	"	4610	"	"	"	5860
6	"	"	"	5560	"	"	"	7070
6.5	24	12	12	6040	30	15	15	7670
7.0	"	"	"	6520	"	"	"	8270
7.5	"	"	"	7000	"	"	"	8870
8.0	"	"	"	7480	"	"	"	9470
8.5	"	"	"	7960	"	"	"	10070
9.0	"	"	"	8440	"	"	"	10670

FIG. 16.



LOAD FACTOR	DEFLECTION IN INCHES												RETREAT			
	A	B	C	D	E	F	G	H	I	J	K	L	RL	RU	LL	LU
3	1.5	1.0	.3	.4	.7	1.2	1.1	.8	.3	.3	.6	.9	-.4	-.2	+.2	+.5
4	2.1	1.4	.5	.6	1.0	1.8	1.5	1.1	.4	.4	.8	1.2	-.6	-.1	+.1	+.6
5	2.6	1.7	.7	.7	1.3	2.3	2.1	1.3	..5	.5	1.0	1.6	-.8	-.1	-.1	+.7
6	3.1	2.0	.8	1.0	1.9	3.1	2.3	1.4	.5	.6	1.4	2.2	-1.1	0	-.4	+.8
6.5	3.5	2.3	1.0	1.2	2.1	3.5	2.5	1.7	.7	.7	1.5	2.5	-1.2	+.1	-.6	+.7
7	3.9	2.6	1.1	1.3	2.4	3.9	2.8	1.7	.7	.8	1.6	2.7	-1.4	+.1	-.7	+.8
7.5	4.1	2.8	1.4	1.6	2.9	4.5	2.9	1.8	.8	.9	2.0	3.2	-1.7	+.0	-1.0	+.8
8	4.5	3.1	1.6	2.0	3.9	5.9	2.8	1.7	.9	1.2	2.6	4.2	-2.2	+.0	-1.7	+.8
8.5	5.4	3.7	2.0	2.6	5.3	8.0	3.1	2.0	1.3	1.7	3.6	4.4	-3.6	-.2	-2.5	+.8
9	HELD.															

AT A LOAD FACTOR OF 8.5 THE UPPER LONGERONS IN BACK OF ENGINE PLATE BUCKLED.

FIG. 17.—Tabulated results of the high angle of incidence static test of the Loening PA-1.

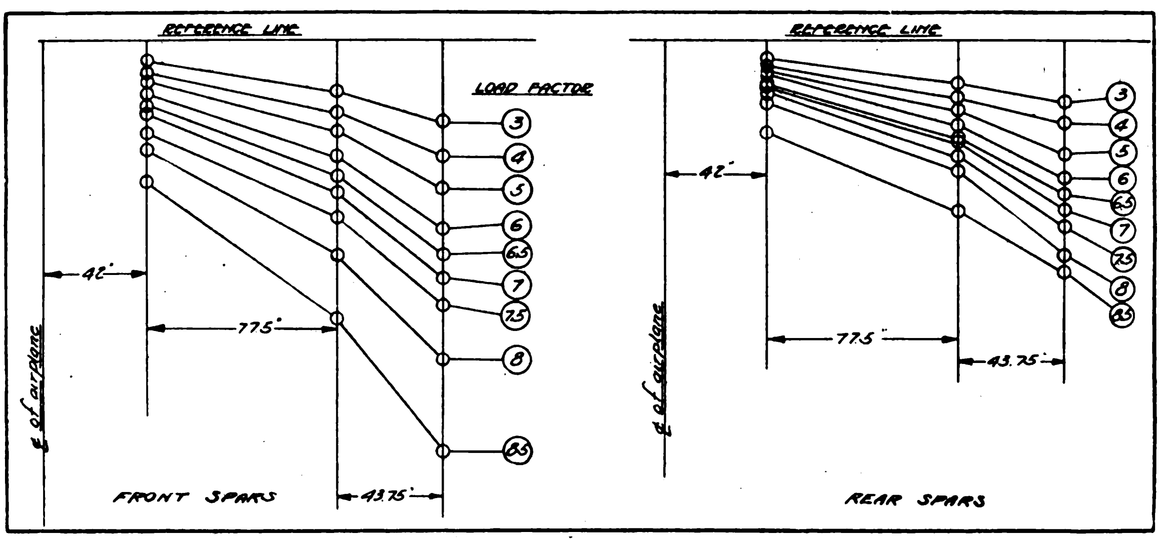


FIG. 18.—Curves showing mean deflection of the wing spars during static test for high incidence condition of the Loening PA-1.

The strength properties as computed from the test data are lower than the average for good spruce and the lower rear spar was exceedingly brash. The modulus of rupture as computed is as follows:

Spar.	Modulus of rupture pounds per square inch.
Lower rear	4,875
Upper rear	7,180
Lower front	7,270
Upper front	7,720

CONCLUSION.

The wing cellule passed the test satisfactorily.

PROCEDURE FOR TEST (LEADING EDGE).

A 6-foot section was cut from the upper wing after the static test of the cellule was complete. This section was supported in an inverted position, with points of support at the spars.

The load on the leading edge was counterbalanced by shot bags placed on the wing along the rear spar.

The factor of failure was computed as follows:

> One-half of the load per running foot on the wing from which the section was taken, was considered the unit factor per running foot of the leading edge.

RESULTS.

The leading edge failed at a factor of 16.6 (Figs. 19 and 20).

CONCLUSION.

The leading edge stood the test satisfactorily, being 18 per cent stronger than the minimum requirements.

AILERONS.

DESCRIPTION.

The two ailerons are mounted on the lower wing by means of three hinges. The type of hinge is shown in Figure 21. Control is accomplished by means of flexible wire cables. Figure 22 shows the assembled framework and Figure 23 the type of rib and the control mast.

Each aileron has an area of 8.1 square feet and a weight of 6.125 pounds. (0.77 pounds per square foot).

PROCEDURE.

The aileron was assembled on the wing as for flight. A spring balance was connected to the control stick by means of which the pull necessary to actuate the aileron was measured.

RESULTS.

Load required 35 pounds per square foot.

At a load of 15 pounds per square foot the pulley brackets bent out of shape and showed signs of pulling away from the spar. The two ribs further out from the compression rib buckled. At 20 pounds per square foot the spar was distorted to such an extent that it split as shown in Figure 24. With the control system discontinued and a rigid connection made to the control mast, the loading was carried to 35 pounds per square foot without failure.

DISCUSSION.

Due to the spar failure it was impossible to finish testing the aileron with the control system connected.

CONCLUSION.

The spar is not strong enough. The pulley bracket and the location of the compression rib are unsatisfactory. The aileron is structurally as strong as required.

RECOMMENDATION.

Redesign the lower rear spars, the aileron control cable pulley bracket, and relocate the compression rib.

ELEVATOR AND STABILIZER.

DESCRIPTION.

The stabilizer is built around a routed spruce spar which supports plywood web ribs. The leading edge is cut from a piece of balsa wood. See Figure 22 for an assembly view of the framework and the two types of ribs. The stabilizer is adjustable.

A built-up spruce and balsa spar carries the ribs and diagonal balsa members which form the framework of the elevators. The balsa members are capped with three-ply plywood. The trailing edge is made from aluminum tubing terminating in the balsa wood end pieces. Figure 25 shows the structure of the elevators. The type of hinge used is shown in detail in Figure 21. Flexible steel cable controls are used. For the weight and area of the horizontal tail surfaces see Figure 26.

The elevator structure weighs 0.75 pounds per square foot and the stabilizer 0.95 pounds per square foot.

PROCEDURE.

The surfaces and control system were completely assembled as for flight. The fuselage was supported so that the longitudinal axis was horizontal. A spring balance with block and tackle attached to the control stick was used to measure the pull required to actuate the elevator under load. Scales were suspended from various points along the edge of the surfaces and by means of a wye level deflection readings were taken.

The load was applied in increments of 5 pounds per square foot up to and including 20 pounds per square foot and then in 2½ pounds increments until failure resulted. The average load per square foot on the elevator was assumed to be two-thirds the average load on the stabilizer. The stabilizer load was assumed to be uniform, and that on the elevators as varying from a maximum at the hinge to one-third maximum at the trailing edge, which results in a center of pressure location for unbalanced surfaces at five-twelfths of the mean chord.

RESULTS.

Stabilizer adjustment was possible up to and including a load of 10 pounds per square foot. At a load of 15 pounds per square foot the stabilizer adjustment could not be operated. The surfaces held the required average load of 35 pounds per square foot. The load was increased until the elevator failed at a load of 50 pounds per square foot. For tabulated deflection readings and the pull on the control stick required to actuate the elevator see

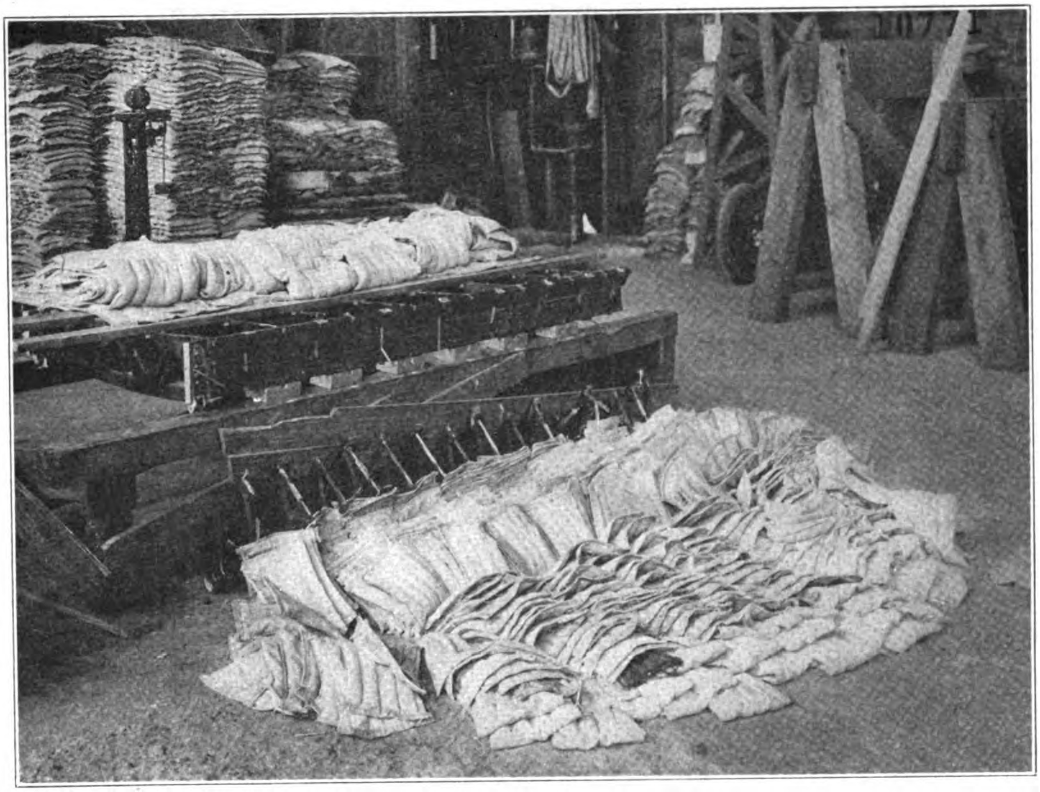


Fig. 19.

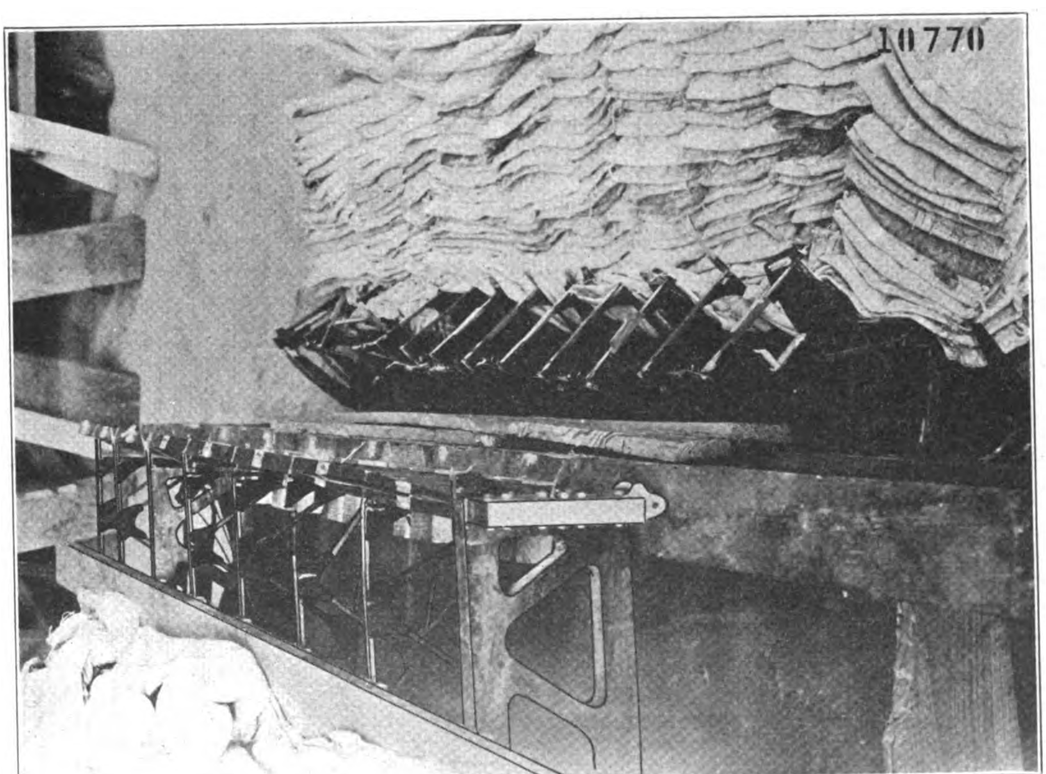


Fig. 20.

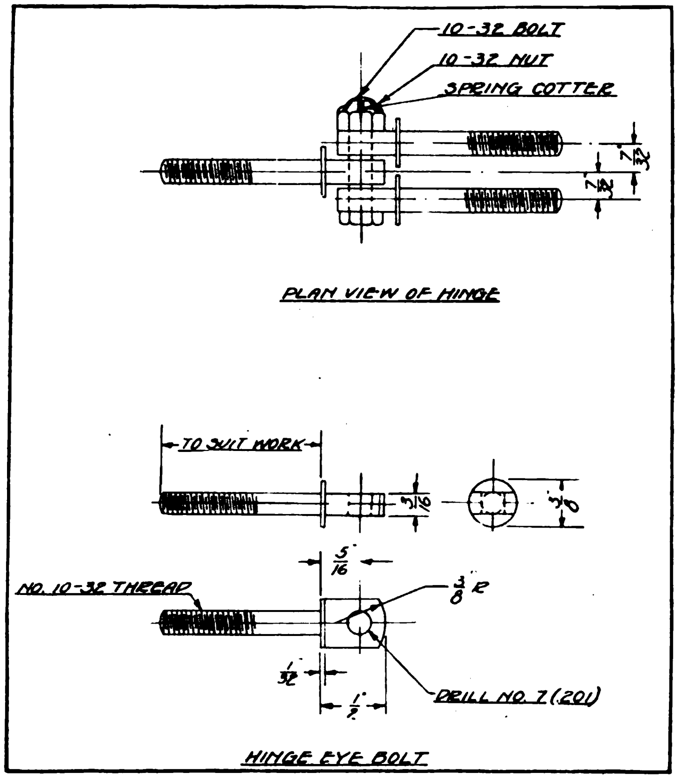


FIG. 21.—Typical control surface hinge of the Loening PA-1.

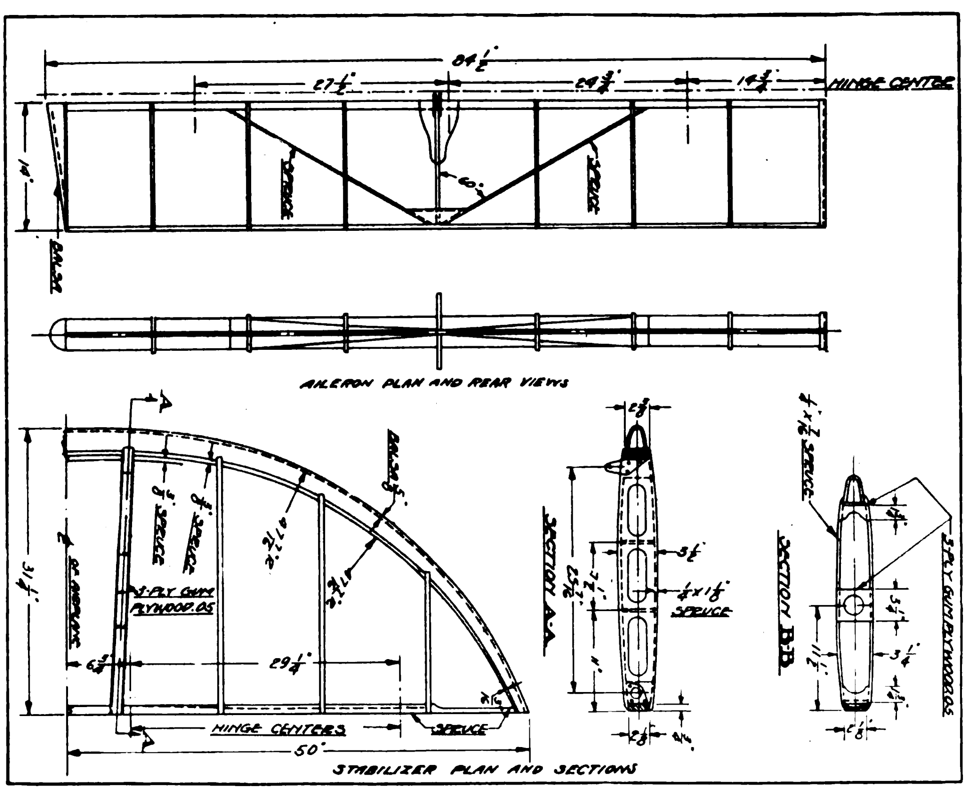


FIG. 22

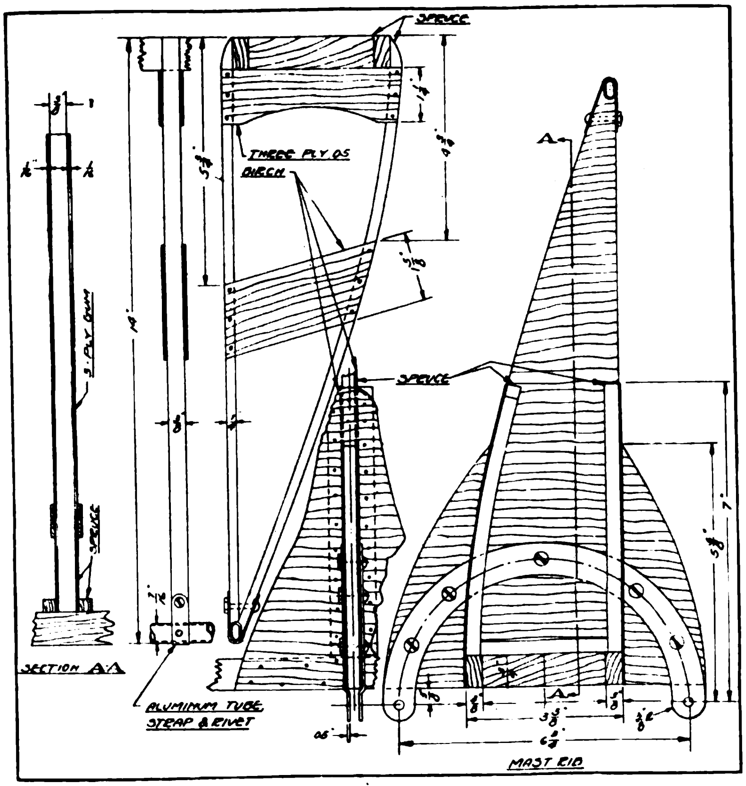


FIG. 23.—Aileron ribs of the Loening PA-1.

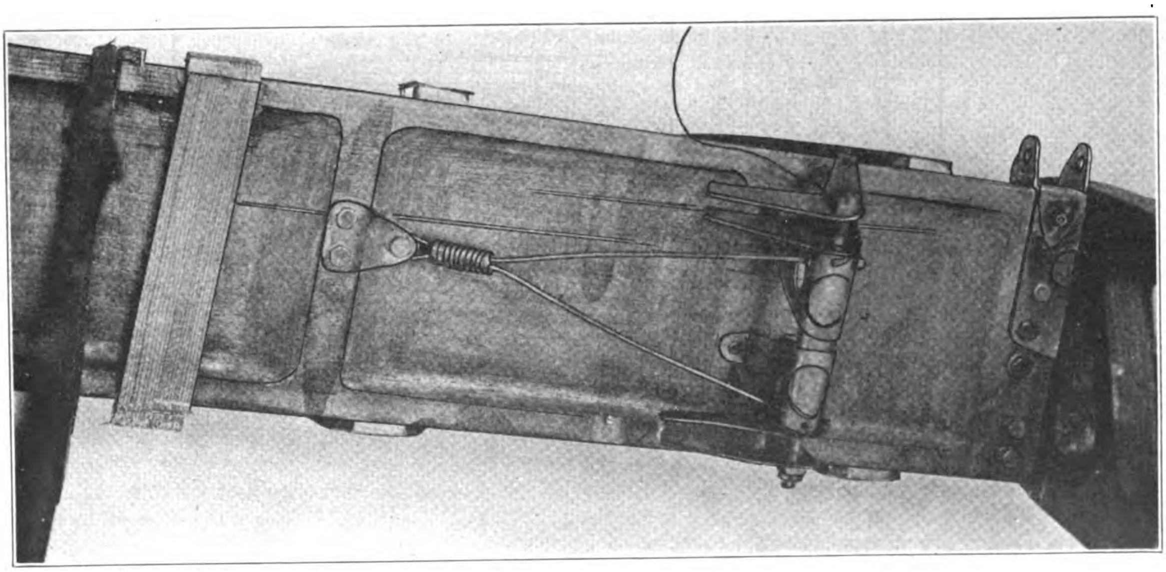


FIG. 24.

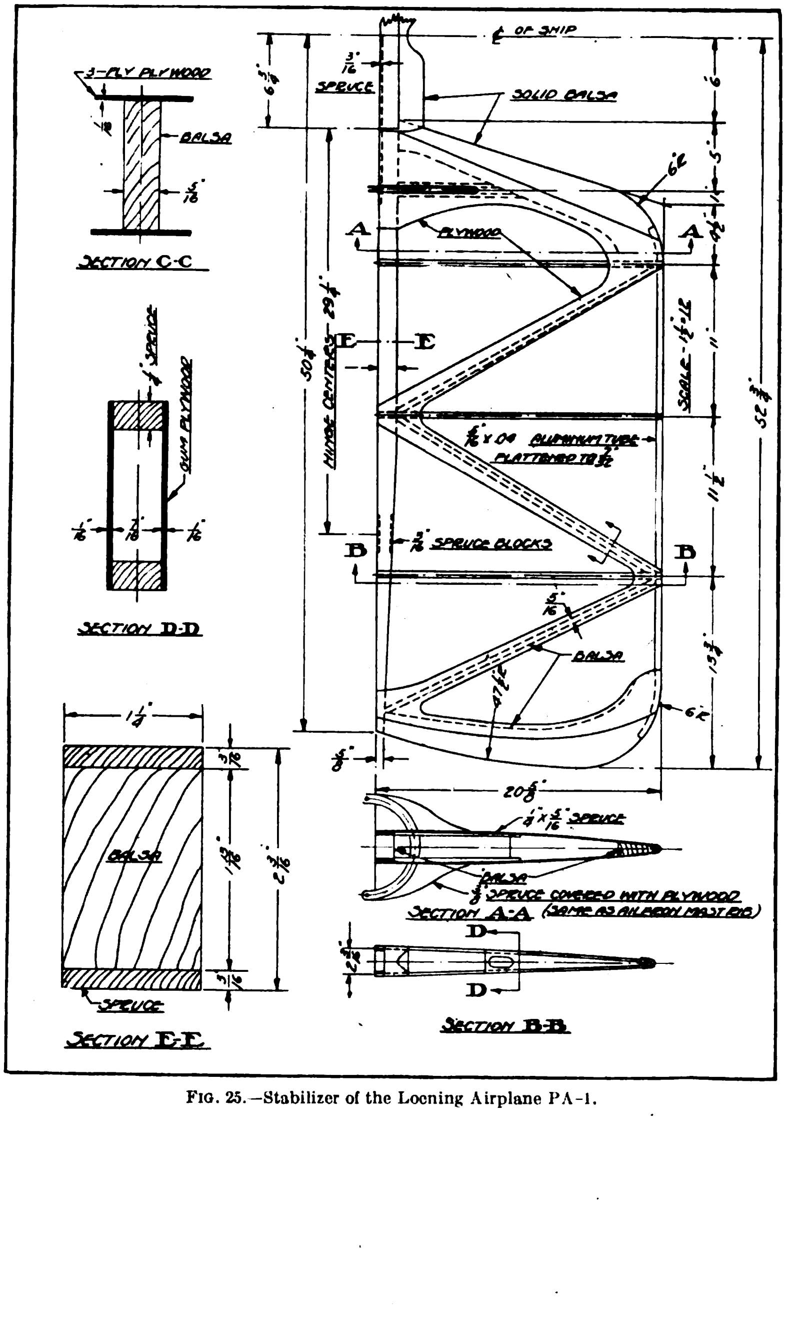


FIG. 25.—Stabilizer of the Loening Airplane PA-1.

figure 26. The failure, with both sides of the elevator broken, is shown in figure 27.

CONCLUSION.

The horizontal tail surfaces and the control system are satisfactory.

RUDDER.

DESCRIPTION.

The balanced rudder is the only vertical tail surface. In terms of the total area of 8.1 square feet the balanced portion constitutes 14.4 per cent. The structural members are of mild steel tubes welded together. The lower part of the rudder fairs in with the rear of the fuselage. Control is obtained by means of flexible steel cables from the rudder bar to the control cable masts. Figure 28 is an assembly of the rudder framework.

PROCEDURE.

The rudder was assembled to the fuselage as for flight. To one end of the rudder bar the control cable was connected, to the other a spring balance with block and tackle by means of which the force necessary to actuate the rudder under load was obtained. The fuselage was firmly supported on its side so that it would not tip over. At the points indicated in figure 29 scales were suspended in order that the deflection readings could be taken by means of a wye level. The balanced portion is loaded one and one-half times the average load per square foot on the unbalanced portion. The load on the unbalanced portion is distributed in the same manner as that on the elevator.

RESULTS.

The rudder supported the required load of 30 pounds per square foot without failure. The loading was continued until failure of the ribs resulted at 47.5 pounds per square foot. Figure 29 gives the pull necessary to actuate the rudder under load and the deflection of the surfaces at the points indicated. Figure 30 is a photograph of the rudder failure with the fabric cover removed.

CONCLUSION.

The rudder and the controls held the required load satisfactorily.

FUSELAGE.

DESCRIPTION.

The all-metal fuselage has four steel tubular longerons. The ends of the tubular compression struts are inserted in holes cut through the wall of the longerons, as shown in figure 31. The brace wires are wrapped around the tubular members and drawn tight by means of turnbuckles. Figure 31 shows the structural assembly and a typical joint between a compression strut and longeron. The engine bearer is formed from a three-sixteenth inch sheet of aluminum and the rear end plate of the fuselage is made from the same material.

The fuselage weights follow:

	Pounds.
Fuselage structure, including engine bearer and end plate	92.5
Cowling and fairing	17.5
Furnishings	28.9
Total weight of fuselage	138.9

PROCEDURE.

The fuselage was supported in a test jig at the points where the flying wires connect to the spars. After these points had been loaded to their carrying capacity, points where the wings are attached to the fuselage were used as additional supports.

The load was applied at five points, A to E, inclusive, figure 32, according to the loading schedule. Scales were suspended from four points, figure 32, from which deflection readings were taken by means of a wye level. The load increments were supported for five minutes before readings were taken.

RESULTS.

When the jacks were let down at a load factor of 4, the right upper wing spars failed in compression, the ribs failed in compression, and a drift wire pulled in two. A load factor of 7.5 was supported for three minutes, when a wire in the second to the last bay, left side, failed. The wire was replaced, and after supporting a factor of 8 for five minutes failed again. With a three-sixteenth inch flexible steel cable in place of the wire the test was continued. The lower longerons buckled in the third bay from the tail end, at a factor of 8. Figure 33 is a photograph of this failure.

DISCUSSION.

Two longerons were sent to the Material Section for physical and chemical tests. The following results received:

Yield point	(1)...... 60,280	(2).... 53,790
Ultimate strength	(1)...... 69,660	(2).... 6[illegible],910
Elongation in 2 in.	(1)...... 19%	(2).... 19%
Elongation in 4 in.	(1)...... 13%	(2).... 13.75%
Elongation in 8 in.	(1)...... 8.38%	(2).... 12.25%

Chemical composition.

Specimen.	Carbon.	Manganese.	Phosphorus.	Sulphur.
(1)	0.18–0.18	0.35–0.38	0.030	0.051
(2)	.10–.12	.49	.030	.038

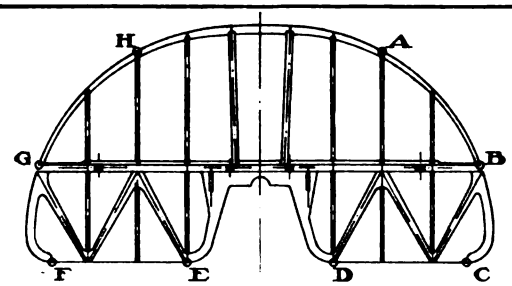
CONCLUSION.

The fuselage stood the required load factor of 7 satisfactorily.

LANDING CHASSIS.

DESCRIPTION.

The landing chassis has spruce struts and spruce cross struts. The cross struts carry the axle fairing. The method of wrapping the shock absorber chord is shown in figure 34, and also the arrangement of the struts and



	WEIGHT IN LBS	AREA IN SQ. FT
STABILIZER	13.0	13.6
ELEVATORS	9.5	12.6

LBS PER SQ FT LOAD	DEFLECTION IN INCHES								LBS PULL ON CENTRE STICK	REMARKS
	A	B	C	D	E	F	G	H		
5	.1	3	4	2	4	4	2	2	20	HAND WHEEL ADJUSTMENT OK
10	2	.5	17	1.1	1.3	18	4	3	45	HAND WHEEL TURNS VERY HARD.
15	3	7	27	13	2.1	28	6	4	70	NO LONGER ABLE TO TURN HAND WHEEL
20	4	10	44	28	3.1	44	.9	5	100	
22.5	4	1.1	49	32	36	5.1	10	5	120	
25.0	.5	1.2	5.9	38	41	59	1.1	.6	140	
27.5	5	13	69	44	49	70	13	.6	160	
30.0	.6	14	74	48	54	78	14	.7	170	
32.5	.6	16	82	54	6.0	8.7	16	8	185	
35.0	7	1.7	9.6	6.5	7.1	10.1	1.7	.9	210	
37.5	8	[illegible]	10.3	69	7.5	10.7	1.8	.9	220	
40.0	8	2.0	12.0	8.4	9.2	12.8	2.0	.9	240	
42.5	HELD									
45.0										
47.5										
50.0	FAILED									

FIG. 26.—Tabulated results of the static tests of the Loening PA-1 elevators and stabilizers.

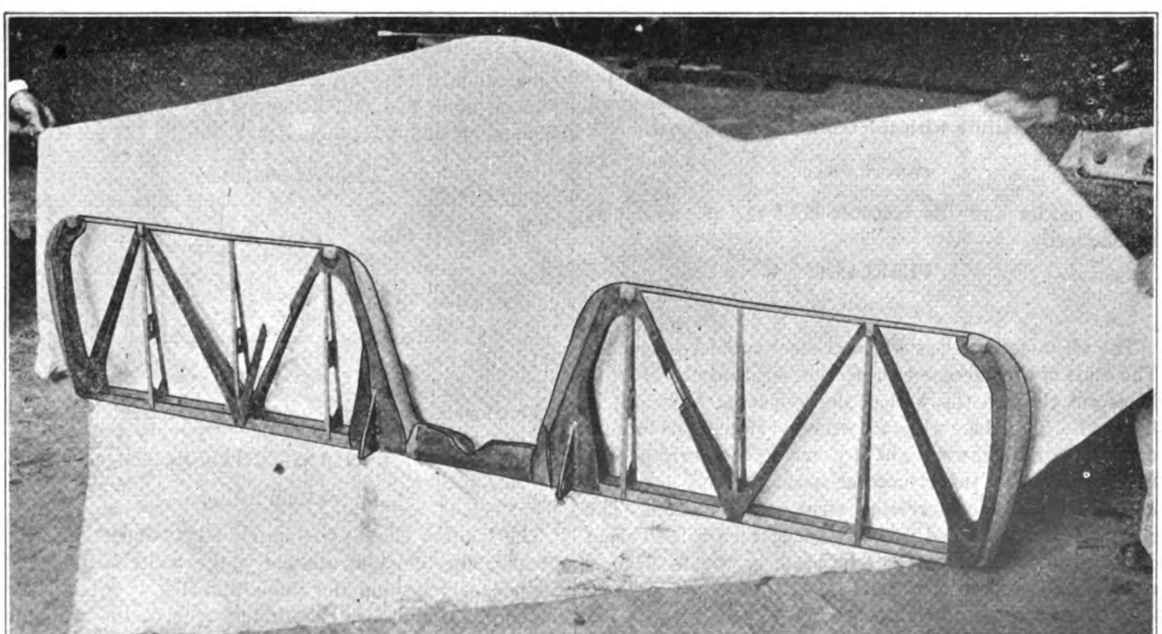


FIG. 27.

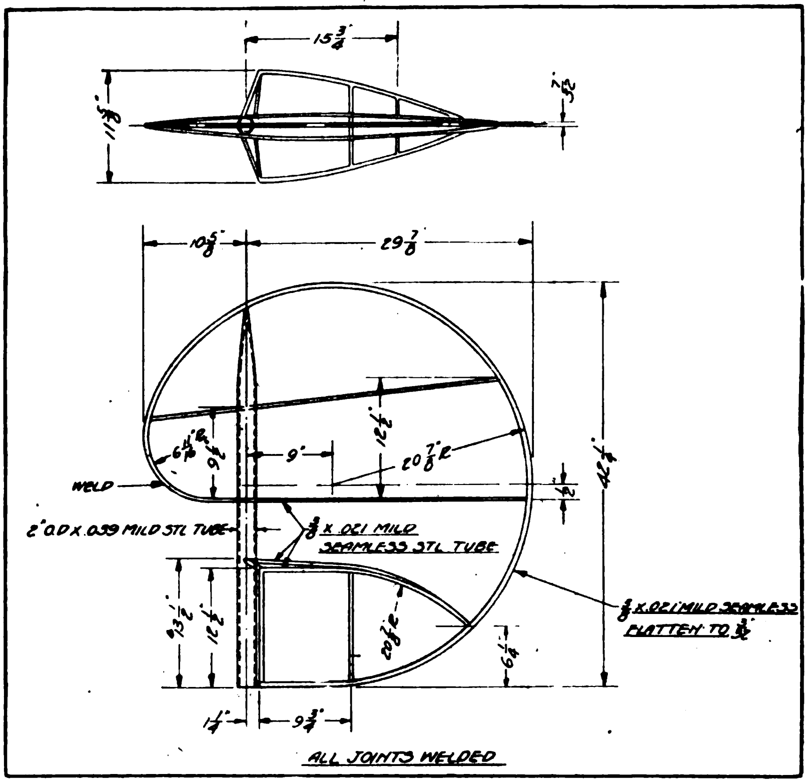
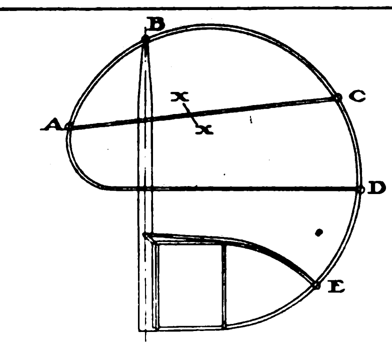


FIG. 28.—Rudder.



WEIGHT - 9.5# AREA OF BALANCED PORTION = 1.17 SQ. FT.
TOTAL AREA = 8.1 SQ. FT.

LOAD IN LBS PER SQ. FT.	POUNDS PULL ON RUBBER BAR	DEFLECTION IN INCHES					REMARKS
		A	B	C	D	E	
5	50	-.1	.2	4	2	2	
10	100	-.2	.3	1.1	1.0	.9	
15	150	-.9	.3	2.9	3.0	2.5	
20	200	-.9	.5	3.1	3.3	2.6	
22.5	220	-1.7	.7	5.1	5.6	4.6	
25.0	240	-1.7	.5	5.0	5.4	4.4	
27.5	270	-2.9	.7	8.0	8.8	7.2	
30.0	290	-2.9	7	8.0	8.9	7.3	
32.5		-3.3	.7		9.6	8.3	
35.0		HELD					
37.5		″					
40.0		″					
42.5		″					
45.0		″					
47.5		FAILED					RIB AT X-X BUCKLED.

FIG. 29.—Tabulated results of the static test of the rudder on the Loening PA-1.

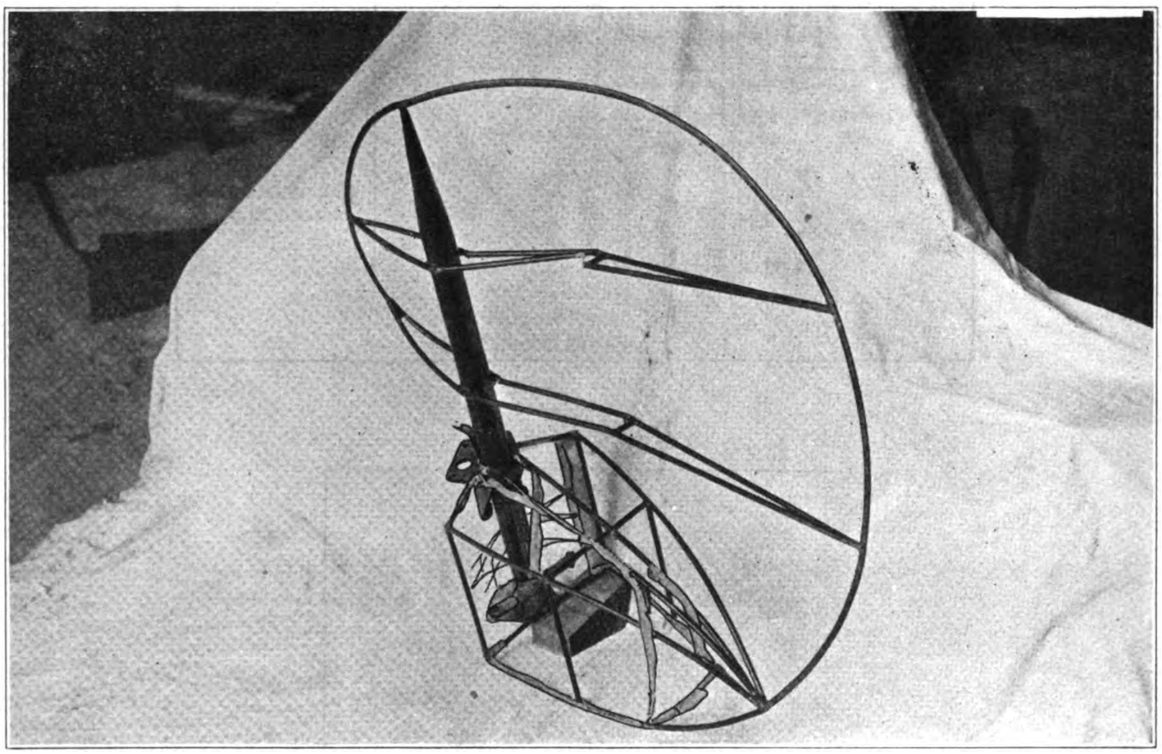


FIG. 30

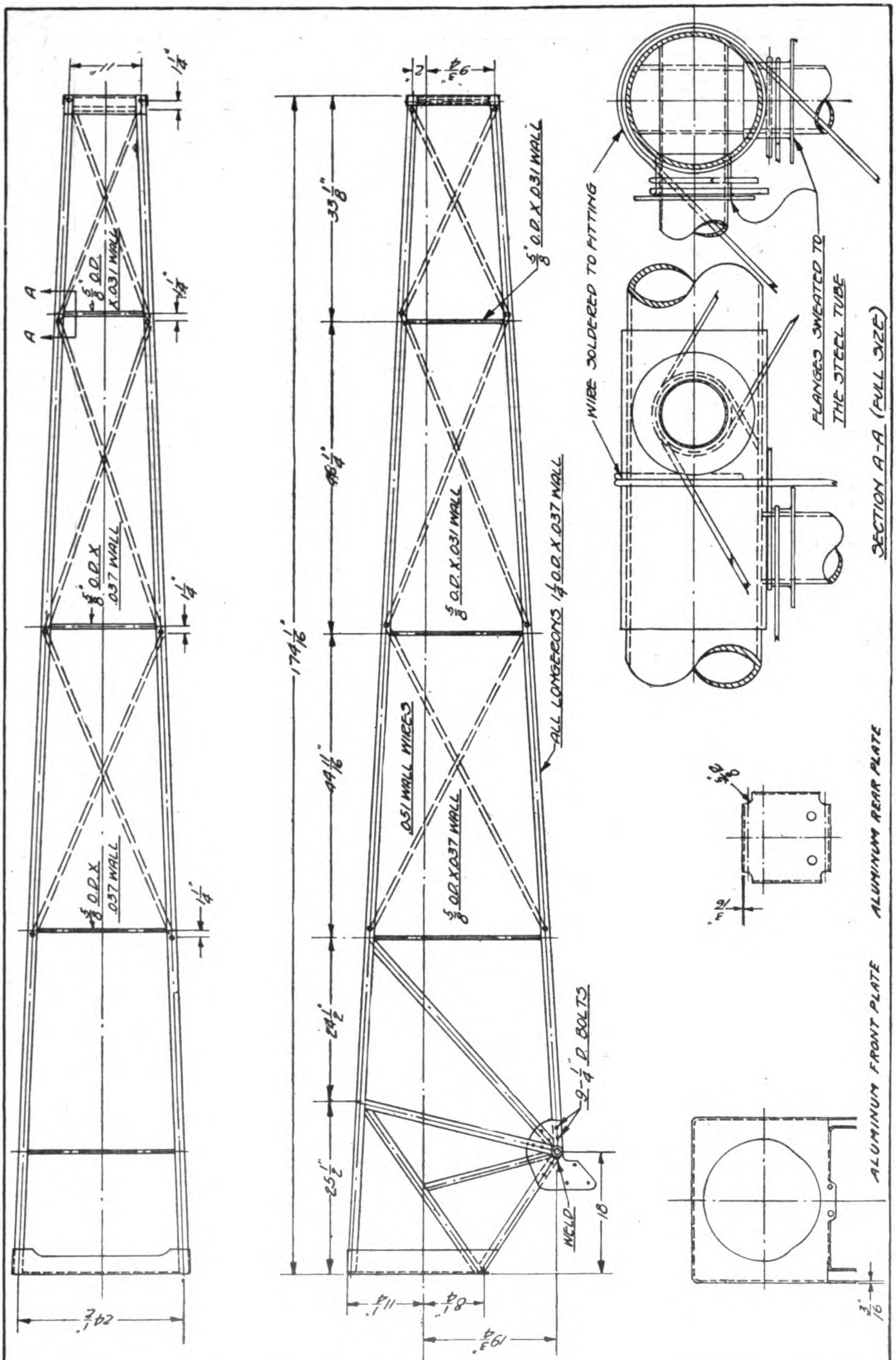
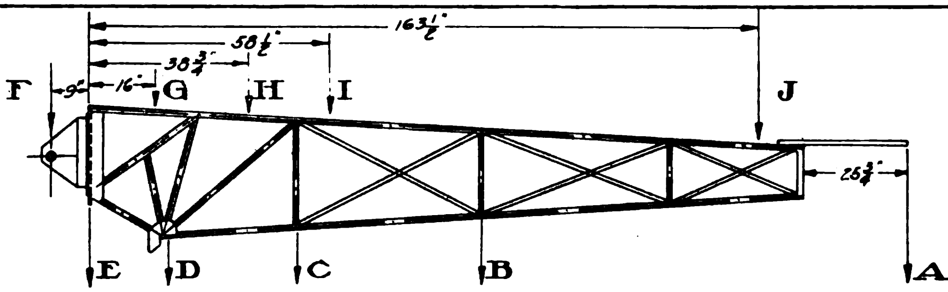


FIG. 31.—Fuselage—Loening PA-1.



LOAD FACTOR	LOADING SCHEDULE					TOTAL LOAD ON FUSELAGE IN POUNDS	DEFLECTION IN INCHES				
	F	G	H	I	J		A	B	C	D	E
2	1800	570	488	90	362	3310	4	4	6	8	1.5
3	900	305	264	45	246	5070	6	.9	1.4	2.4	4.8
4	900	306	264	45	246	6830	1.4	2.1	3.0	4.5	9.0
4.5	450	153	132	22	123	7710	1.2	2.1	2.9	4.8	9.3
5.0	"	"	"	"	"	8590	1.5	2.1	3.0	4.7	9.6
5.5	"	"	"	"	"	9470	1.4	2.1	3.0	4.7	9.8
6.0	"	"	"	"	"	10350	1.5	2.1	3.0	4.8	10.0
6.5	"	"	"	"	"	11230	1.6	2.1	3.0	4.9	10.3
7.0	"	"	"	"	"	12110	1.6	2.2	3.0	5.0	10.7
7.5	"	"	"	"	"	12990	LOAD SUPPORTED FOR 3 MINUTES THEN WIRE FAILED.				

FIG. 32.—Loading schedule and chart of deflections of the Loening PA-1 fuselage during static test.

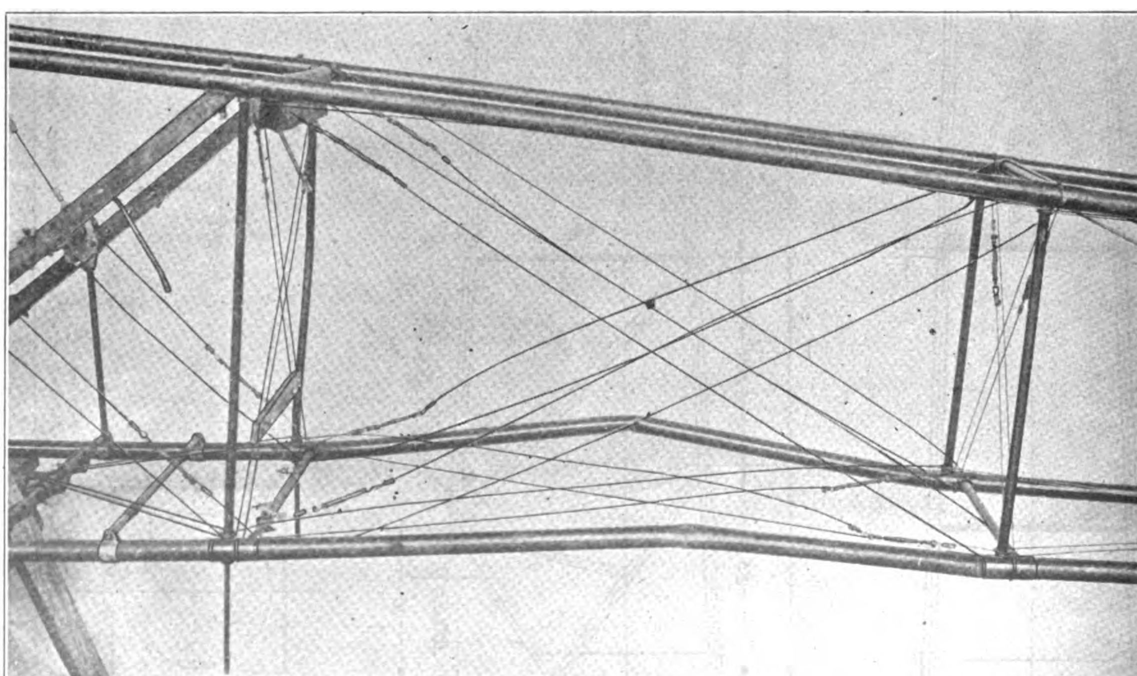


FIG. 33.

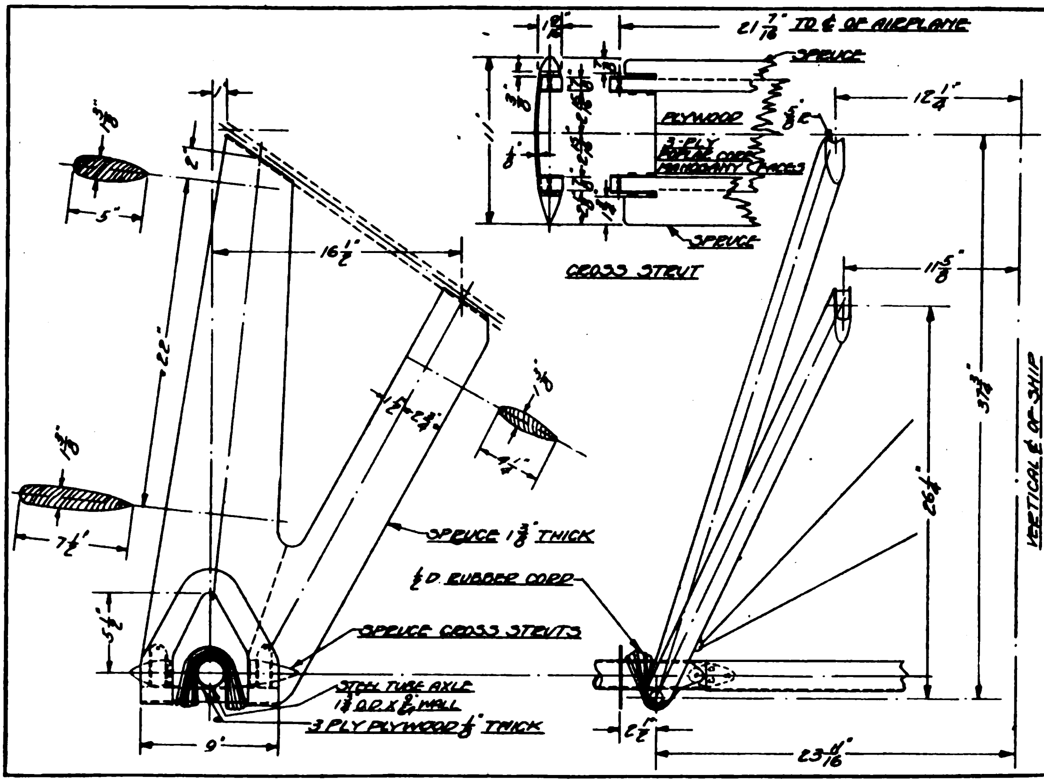
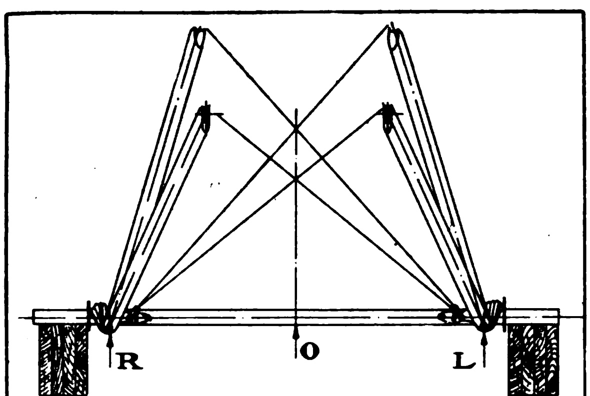


FIG. 34.—Chassis—Loening PA-1.



LOAD FACTOR	TOTAL NUMBER OF POUNDS	DEFLECTION IN INCHES PER LOAD INCREMENT ADDED			REMARKS
		R	L	O	
2	4922	1 3/16	1 1/8	3/8	
3	7383	11/16	7/16	3/4	
4	9844	5/8	5/8	3/4	
4.5	11074	7/16	3/8	7/8	
5	12305	5/16	1/4	1 1/16	
5.5	13503	1/4	3/8	1 1/4	
6.0	14766	1/4	1/4	1 7/16	
6.5	15996	1/4	1/2	1 11/16	
7.0	17227	FULLY EXTENDED	FULLY EXTENDED		PERMANENT SET IN AXLE SHOCK ABSORBERS FULLY EXTENDED

FIG. 35.—Static test results of the Loening PA-1 landing chassis.

their sections at points indicated. The weight of the chassis without wheels is 43.9 pounds. Weight of wheels, 31 pounds.

PROCEDURE.

With the axle in a horizontal position, the chassis was placed in a jig so that a vertical line passed through the center of the axle and the center of gravity of the airplane. The airplane was represented by the load placed on the test jig platform. The wheels were removed and the bearing portion of the axle placed on blocks which supported the landing chassis. Deflections of the shock absorbers and bending of the axle were taken for each load increment after it had been supported for five minutes.

RESULTS.

Tabulated results are given in figure 35. The axle showed a permanent set, and the shock absorber chord was fully extended at a load factor of 6.5 The struts held a load factor of 7 without failure.

CONCLUSION.

The landing chassis held the required load factor of 6 satisfactorily.

File B 63/16

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | August 1, 1922 | No. 359

AIR MEDICAL SERVICE

▽

Compiled by the Medical Section
of the Air Service

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CONTENTS.

AIR MEDICAL SERVICE.

PHYSIOLOGICAL EFFECTS OF ALTITUDE.

By Edward C. Schneider, *Wesleyan University, Middletown, Conn.*

[Figures in parentheses refer to bibliography at end of article.]

Altitude is a climatic condition that causes physiological changes which affect our bodily comforts. Among its variables are lowered atmospheric pressure, partial pressure of oxygen, temperature and humidity; and increased intensity of sunshine and electrical conditions. While in the past the effects of altitude have been attributed to one or more of these variables (15), (37), (104), it is to-day recognized that the controlling element in the physiological reactions is the diminished partial pressure of oxygen and the consequent imperfect aeration of the arterial blood.

The altitude oxygen want is ascribed to two conditions. Primarily it is due to the imperfect saturation of the arterial blood with oxygen, which is the result of reduced atmospheric pressure; but secondarily it becomes temporarily more pronounced because of a chemical change in the blood that prevents as free a passage of oxygen into the tissues as is normally the case. This oxygen want may cause trouble in the body, which is usually soon offset by compensatory reactions that ultimately, if a residence be maintained, lead to acclimatization. The anoxemia, defined (45) as a condition in which the rate of supply of oxygen to the tissues is insufficient, means in many men a temporary slowing down of life.

Barcroft (6) has pointed out that acute anoxemia simulates drunkenness, while chronic anoxemia, which is an oxygen want, perhaps not very great, but that may be continued over months, simulates fatigue. He classifies the chronic types of anoxemia as the anoxic, anemic, and stagnant. In the first the pressure of oxygen in the blood is too low and the hemoglobin is not saturated to the normal extent; in the second the quantity of hemoglobin in the body is too small, but the oxygen pressure is normal; in the third the blood is normal, but supplied to the tissues in insufficient quantities. It is the anoxic type that occurs at high altitudes, and this, according to Barcroft, is the most difficult for the organism to circumvent, since the rate of delivery of oxygen to the tissues depends upon the pressure of oxygen in the blood.

The behavior of the organism under low oxygen depends upon four factors: 1, the suddenness with which the oxygen is decreased; 2, the extent to which it is decreased; 3, the length of time it is decreased; and 4, to some extent, upon the physical condition of the body. These should be recognized in any statement of symptoms of and compensations to altitude. Thus the conscious and outwardly appearing reactions experienced by the aviator and the mountaineer are, as a rule, quite unlike because of the speed as well as the extent of oxygen reduction. The compensations to altitude fall into two categories—namely, the emergency adjustments, based upon temporary functional changes, and the permanent, which, by profound alterations, result in acclimatization. The lowest altitude at which the temporary compensations occur will depend to a considerable extent upon the speed with which the ascent is made and the degree of response upon the height reached. The permanent adjustments require time, and their onset and amount will be determined by the first two factors.

The ability to compensate to the low oxygen tensions of high altitudes varies with the individual, and the adjustments may be more rapid and effective at one time than another. In repeated journeys to the summit of Pikes Peak the author has experienced several degrees of mountain sickness and at other times has escaped the malady. In the United States Army Air Service (2), (3), (68) the experience with the altitude classification test of low oxygen by rebreathing has shown that men who ordinarily compensate well to the low oxygen may pass through a period in which they do poorly. While the differences can not be entirely accounted for, yet without doubt they have many times been associated with health.

Much of our information regarding the effects of altitude has been obtained by methods of investigation that did not necessitate living on the mountains. Various researches (10) have shown that merely to subject the organism to a deficiency of oxygen calls forth the reactions characteristic of altitude. Lutz and Schneider (66) subjected men to low oxygen tensions produced in three ways—by low barometric pressure in a low-pressure chamber which was continuously supplied with fresh air; by a low percentage of oxygen caused by rebreathing air confined to a mechanism in which the normal atmospheric pressure was maintained and from which the carbon dioxide was removed; and by diluting the respired air with increasing amounts of nitrogen. By conducting experiments more or less parallel as to time, rate, and duration, they were able to prove that the circulatory, respiratory, and blood adaptive changes were practically identical in these three methods.

A study of altitude and anoxemia leads to the conclusion that much work has been partially or wholly futile because of unsatisfactory experimental methods. This lack has given a literature full of contradictory theories and conclusions. The space allotted by the editors of this journal makes it impossible to consider many interesting studies.

Only such as bear on recent work will be considered. The reader is referred to Cohnheim (17) and Zuntz, Loewy, Müllar, and Caspari (104) for helpful reviews of many topics.

Attention is called to the fact that expeditions have many times been made to altitudes that were too low to give a satisfactory response, and the time spent at the altitudes has often been too short for the adaptive changes to have progressed sufficiently to be measured. The process of acclimatization has been studied for altitudes only up to 15,000 feet. The most satisfactory returns have come from expeditions made to 14,000 feet or higher. The results obtained by a short sojourn at 6,000 to 10,000 feet have been, as a rule, unsatisfactory. Our knowledge of more acute oxygen want, as experienced in flying, includes altitudes up to those that cause unconsciousness.

The responses of the organism to the anoxemia of altitude involve the respiration, blood, and circulation, and are: 1, a fall in the alveolar carbon dioxide pressure and a rise in the alveolar oxygen pressure, which are associated with an increase in the ventilation of the lungs; 2, an increase in the percentage and the total amount of hemoglobin in the blood; 3, a modification in the proportion of acids and bases in the blood; and 4, an increase in the rate of heart beat, with which are also associated other circulatory changes. Each of these has been considered to be in the nature of a compensation, so that the tissues may be more adequately supplied with oxygen. The respiratory changes raise the oxygen pressure to which the blood is exposed; the increase in hemoglobin provides for more oxygen in a given unit volume of blood; the chemical changes provide the conditions for an adequate dissociation of oxyhemoglobin in the tissue capillaries; and it has been thought that the circulatory changes result in an increased volume of blood flow, which would raise, to a slight extent, the oxygen pressure in the tissues.

It has been found that under the conditions of flying the respiration and circulation are the first mechanisms to be stimulated, and they are almost equally sensitive to relatively low altitudes; while at higher altitudes the blood may also concentrate (42). During residence at a high altitude, the respiration is the first function affected and may even begin to change during the ascent. Ordinarily in the mountaineer the beginnings of the blood and circulatory changes are delayed by at least as much as 6 to 24 hours. There is evidence that the most temporary of the several changes are those affecting the circulatory system. In the interactions of the several physiologic functions concerned in acclimatization, the circulation alone tends to return to the low altitude normal; while the other functions continue on at the new levels as long as residence at the altitude is maintained.

SYMPTOMS NOTICEABLE AT HIGH ALTITUDES.

When anoxemia is produced gradually and rapidly as in an airplane ascent the effects are insidious and easily overlooked. In fact many aviators find it difficult to analyze their sensations and are not sure that altitudes produced any effect. This is because the most striking action is on the nervous system. The first effect is stimulation and results in a feeling of well-being, but this stage gradually and insensibly passes into sensory and mental dullness (3), (4), (12), (65). At 12,000 feet the aviator may be conscious of breathlessness, a little higher he feels muscular weakness when moving, there may be a headache and a tendency to Cheyne-Stokes breathing. As he continues to ascend memory and judgment are gradually impaired, while sight and hearing become dulled. Many men experience an overpowering desire to sleep, while fainting is not uncommon. Unfortunately the aviator often becomes possessed with fixed ideas and being unable to reason does foolish things. To then continue to ascend means loss of consciousness. Between 23,000 and 25,000 feet appears to be the upper altitude limit for consciousness for unacclimatized men.

There are after effects of an altitude flight that are of special interest, such as unusual fatigue, subnormal breathing in which the rate and depth are decreased, subnormal blood pressure, and headache.

The mountaineer ascends more slowly and, unlike the aviator, is liable to an attack of "mountain sickness." The first effect as in a rapid ascent is stimulating. When the traveler arrives at the summit of a mountain such as Pike's Peak, altitude 14,110 feet, he may feel unusually well and exhilarated, often showing a disposition to be talkative, unreasonable, or quarrelsome. His lips are blue, he is unusually sensitive to cold, feels light-headed, and may have a headache. As the day passes, in six or eight hours, lassitude is felt: the headache, which is frontal, gets worse; the appetite fails; there is likely to be nausea and vomiting; and frequently there is a sense of oppression in the chest and a rapid pulse. There is always depression, more or less muscular weakness, and sometimes complete prostration. The next morning the eyes are dull and heavy, temperature subnormal, the tongue furred, and the bowels disturbed. This condition may last a day or two, and if the patient remain quiet the attack is soon over. Strauch (88), having reviewed the mountain sickness experiences of early explorers, calls attention to the fact that this malady befalls some individuals at a lower, others at a higher altitude; but that for all there is a critical line beyond which escape is impossible. In some it may occur at 10,000 feet, while only a very few can venture to 19,000 feet without the experience.

Ravenhill (75) who had a large experience among the Andes Mountain mining camps at 15,400 feet describes, in addition, a cardiac and a nervous type of mountain sickness; the former is characterized by acute heart failure and the latter by persistent vertigo, trembling, and even convulsions.

THE RESPIRATION AT HIGH ALTITUDES.

The early observations on the influence of altitude on respiration dealt mostly with the rate, depth, and per minute volume of breathing and have shown that the amount of change varies with individuals (26), (36), (70), (104). Altitudes up to 15,000 feet either slightly increased or decreased the rate of breathing; the depth of breathing as a rule was increased although in some men the opposite resulted; and the per minute volume of breathing was found to be increased, but when corrections were made for temperature and pressure by reducing the volume to 0° C. and 760 millimeters the volume of breathing at 15,000 feet was from 10 to 78 per cent less than at low altitudes.

Altitude and other types of low oxygen studies have thrown much light on the method of control of respiration. To Haldane is due the credit of initiating the study which has given not only the facts but also very largely our present day interpretations. At low altitudes a close relationship exists between the alveolar tension of carbon dioxide and the per minute volume of breathing; the two vary proportionately, but the carbon dioxide tension remains rather constant. However, at high altitudes the opposite relationship obtains, the alveolar carbon dioxide is decreased while the breathing is increased. This difference is based upon blood changes. The alveolar air changes in carbon dioxide and oxygen can be used to determine just when and to what degree the respiration responds to altitude. Zuntz and coworkers (104) and Durig's (26) Monte-Rosa Expedition in 1906 determined, by indirect methods, that the alveolar carbon dioxide is lowered as the barometric pressure falls; but it required the more exact and direct method of Haldane and Priestley (47) to follow the changes in detail. The direct method was early applied by Boycott and Haldane (14) in a low pressure steel chamber, and later by Ward (98) on Monte Rosa, and by the Anglo-American Expedition (23) on Pikes Peak.

The members of the Anglo-American Expedition at 14,110 feet already showed a fall in the alveolar carbon dioxide when the first analysis was made in from 30 to 60 minutes after arrival on the summit. This indicates that the respiratory response began during the journey up the mountain. However, the process was then by no means completed. The average CO_2 tension upon arrival was 32.8 millimeters; this was followed by a gradual fall for from 3 to 19 days when it went to between 25.4 and 29.5 millimeters. In all cases the alveolar tension of oxygen was of course least the first day or so, ranging from 40.2 to 47.1 millimeters; and then gradually rose as the CO_2 tension fell, reaching finally from 54 to 56.4 millimeters. This rise in alveolar oxygen pressure is one of the important events of acclimatization. Had the sea level CO_2 tension of 40 millimeters been maintained at 14,110 feet, the alveolar oxygen pressure would have been only 36 millimeters. The new regulation gradually raised the alveolar oxygen pressure a little more than 16 millimeters above what it would otherwise have been.

A fall in the alveolar CO_2 tension indicates an increase in the per minute volume of breathing. The Anglo-American Expedition found that one individual breathed per minute in bed at sea level 7.7 liters; and when acclimated at 14,110 feet, 10.2 liters; when standing at rest at sea level 10.4 liters; and at 14,110 feet, 14.9 liters.

Miss Fitzgerald (32), (33), from a study of acclimated inhabitants of many altitudes found that the alveolar CO_2 pressure diminishes as altitude increases. She formulated the law that for every fall of 100 millimeters in the barometric pressure there is approximately a fall of 4.2 millimeters in the alveolar carbon dioxide pressure. This means that approximately a 15 per cent increase in the ventilation of the lungs occurs for each 5,000 feet increase in altitude.

During rest, in the acclimatized person, the breathing is ordinarily modified only in depth. During physical exertion the rate increases more rapidly than in the same exercise at sea level. Thus one subject when standing at sea level breathed 17 times per minute, on Pike's Peak 20 times; walking at the rate of 4 miles per hour at sea level 17.2, on Pikes Peak 29 times; and at the rate of 5 miles per hour at sea level 20, and on Pikes Peak 36 breaths per minute. The increase in the volume of breathing for the same conditions were: standing at rest at sea level 10.4, on Pike's Peak 14.9 liters; walking at 4 miles per hour at sea level 37.3, on Pike's Peak 57 liters; walking at 5 miles an hour at sea level 60.9, and on Pike's Peak 110.2 liters per minute. These figures make it clear that excessive hyperpnea is experienced on exertion during a sojourn at 14,000 feet, but this becomes less marked after the first day or two.

The consumption of oxygen during such exertions is approximately the same for each degree of effort at sea level and the high altitude. Most of the investigations show that metabolism is independent of variations in barometric pressure (23), (27), (28), (36), (53), (92), (104).

By means of experiments conducted in a low-pressure steel chamber and by low percentages of oxygen at normal atmospheric pressure, Lutz and Schneider (66) have attempted to simulate the rate of ascent of an aviator to 18,000 or 20,000 feet. The alveolar CO_2 pressure and the per minute volume of breathing were found to be changed at 656 millimeters barometric pressure (4,000 feet). Ellis (30) by the rebreathing method secured as early a response. It appears, then, that the respiratory response of increased breathing is stimulated almost at once by altitude during flying. The alveolar carbon dioxide and oxygen tensions fall progressively during an ascent to 20,000 feet, the carbon dioxide from an average of 39.7 to 30 millimeters and the oxygen from an average of 103.2 to 34.8 millimeters. The oxygen pressure in the blood as it leaves the lungs would average, according to Barcroft (6), 5 millimeters less than the alveolar oxygen pressure. So we have in the alveolar oxygen pressure, by referring to the normal dissociation curve, a measure of the degree of saturation of the arterial blood with oxygen and, therefore, of the degree of anoxemia.

In an assent of short duration, such as an airplane flight, if a high level be maintained for an hour or more there is a tendency for the alveolar carbon dioxide tension to rise somewhat and the per-minute volume of breathing to decrease toward normal. Ellis (30) and Lutz and Schneider (66) correlate these changes with the appearance of other compensations to low oxygen that are advantageous to the subject, while Haldane, Kellas, and Kennaway (49) attribute this falling off in the breathing to a washing out of preformed CO_2 from the blood by the increased breathing.

The after effects on the respiration of a stay at a high altitude of one or two hours are of short duration. Lutz and Schneider with low pressure chamber experiments found that, in a stay of from 30 to 90 minutes at a pressure corresponding to 15,000 feet, in four out of five subjects the alveolar air CO_2 was back to normal within 20 minutes after returning to 760 millimeters, while in only four out of nine cases was the return made in the same time after a stay at 18,000 feet. It has been a common observation among aviators that breathing is subnormal for awhile after landing. In that time the organism is making up the loss in CO_2 and recalling alkali into the blood. There is evidence that relatively permanent factors of adaptation soon begin to relieve the more temporary compensations. Thus Boycott and Haldane (14) report a case held 24 hours

at 545 millimeters in a low-pressure chamber in which the alveolar CO_2 pressure had scarcely returned to normal after two days. The persistence of the after-effects has been noted after residence on a mountain by Ward (98) and by the Anglo-American Expedition (23). The most conspicuous case was reported by Schneider (78) for a man who had lived six months on the summit of Pike's Peak. This man continued to show a hyperpnea for at least four weeks, in which time his alveolar CO_2 tension gradually rose from 27.1 to 37 millimeters. While the aviator breathes subnormally, the mountaineer ventilates his lungs excessively during the period of "after effect." The former has an alkalosis of the blood and the latter a high ratio of fixed acids to bases. The mountaineer very likely is slowly accumulating blood alkalies and increasing the blood content of volatile acids.

Periodic breathing is frequently observed among newcomers at very high altitudes. This was first observed by Mosso (70), and later studied by Douglas (21) and by the Anglo-American Expedition. It no doubt is caused by want of oxygen, in that it has been abolished by the administration of pure oxygen.

VITAL CAPACITY.

Authorities agree that a decrease in the vital capacity takes place with a lowered barometric pressure, but the explanations as to cause differ. Zuntz and coworkers (104) explain this change as being due to the expansion of intestinal gases. Durig (26) leans toward fatigue of the respiratory muscles as the true explanation. Fuchs (36) finds cause in an increase of muscle tone due to low temperatures. Durig and Zuntz (27) later accept in part this viewpoint. Experiments in low-pressure chambers give a similar reduction. Schneider (68) by this means has shown that the breathing of oxygen prevents a part of the decrease.

OXYGEN SECRETION BY THE LUNGS.

Opinion has been divided as to the means by which the passage of oxygen into the blood is effected at high altitudes. One group, the larger, has maintained that both at low and high altitudes the oxygen enters the blood solely by diffusion through the pulmonary epithelium; whereas the other group has maintained that diffusion alone can not account for the intake of oxygen, but that it is supplemented by an active secretion of oxygen by the pulmonary epithelium. The secretory theory has received its support from observations of the Anglo-American Pikes Peak Expedition. It is admitted that, if the oxygen pressure in the blood be higher than in the alveolar air, only the secretory theory will account for this difference. In order to measure the partial pressure of oxygen in the blood of men on Pikes Peak, Douglas, Haldane, Henderson, and Schneider (23) used the indirect method of Haldane and Smith (46), as modified by Douglas and Haldane (22), in which the administration of carbon monoxide and the law of mass action are employed to determine the partial pressure of oxygen. By this means they found the average excess of oxygen pressure in the arterial blood was 35.8 millimeters, the mean normal resting alveolar oxygen pressure 52.5, and the arterial pressure 88.3 millimeters. They also used the then known facts regarding diffusion of oxygen and found that alveolar oxygen pressure at that altitude would not deliver oxygen to the blood rapidly enough to supply the bodily needs, especially during exercise. To-day it appears that these results and conclusions were based on untrustworthy assumptions. Dr. Marie Krogh (60) in 1915 established a new diffusion-coefficient for the passage of oxygen through a membrane and showed that, if the figures were correct, it was possible for diffusion to account for the passage of a sufficient amount of oxygen to supply the body needs up to such altitudes as 24,000 feet. The theory so far as altitudes are concerned was from then on only supported by the indirect evidence that the oxygen pressure in the arterial blood was higher than in the alveolar air. More recently Barcroft, Cooke, Hartridge, and Parsons (9) drew blood directly from the radial artery of the wrist of a man who had lived 6 days under an oxygen pressure of 84 millimeters. By carefully controlled methods the oxygen pressure of the blood was determined by two direct methods of measurement—the blood-gas pump and the differential blood-gas apparatus. They conclude that "The arterial blood *in vivo* contained less oxygen both during rest and work than did samples of the same blood exposed to alveolar air *in vitro* at body temperature." So for the present it appears that the burden of proof for the theory of oxygen secretion by the lungs lies with its advocates.

THE BLOOD CHANGES.

The extensive literature on the blood is discordant, some maintaining that altitude is entirely devoid of effect and others insisting that extreme changes occur. This lack of agreement is most conspicuous regarding the changes in the number of red blood cells. A good review of the early literature is given by Bürker, Jooss, Moll, and Neumann (15). Their work emphasizes the necessity of employing experimental methods of a high degree of accuracy.

ERYTHROCYTES AND HEMOGLOBIN.

As early as 1878 Paul Bert (10) predicted that the blood of man and animals living at high elevations would be found to have a greater oxygen capacity than that of similar individuals at sea level. In 1882 (11) he showed that the blood obtained from several kinds of animals living at a high altitude in Bolivia had a greater oxygen capacity than that taken from animals at sea level. A little later, in 1890, Viault (95) reported an increase in the number of red corpuscles per cubic millimeter of blood in man and animals at an elevation of 14,400 feet in Peru; while Müntz (72) found that the blood of animals living at an altitude of 9,400 feet in the Pyrenees contained a larger percentage of iron than that of those at low levels.

While these early observations have from time to time been controverted, at the present time the evidence for an increase in the erythrocytes and hemoglobin is overhelming.

The relation between the increase in the number of erythrocytes and amount of hemoglobin has also been a subject of debate. Schaumann and Rosenqvist (77), Oliver (73), VanVoornveld (96), and Fuchs (35) found that the increase in red cells exceeded that of hemoglobin, while Eggers (29) and Dallwig, Kolls, and Loevenhart (20) report a much smaller increase in red cells than in hemoglobin. The Anglo-American Pikes Peak (23) Expedition in 1911

found the red corpuscles to increase in equal proportion with the hemoglobin, so that there was no alteration of the color index. Bürker (15) and collaborators at 6,150 feet found the erythrocytes to increase 4 to 11.5 per cent and the hemoglobin 7 to 10 per cent. Cohnheim (18) and Schneider and Havens (82) find the two changes run parallel. It is to be expected that as more exact methods of determining the hemoglobin come into use it will be shown that the color index is not changed with altitude.

If the increase in erythrocytes and hemoglobin prove to be parallel, then Miss Fitzgerald's (32) law may be accepted as a measure of these blood changes. She found that for every 100 millimeters fall in atmospheric pressure there is, among acclimated inhabitants, an average rise of about 10 per cent in hemoglobin and that this rise is approximately the same for men and women.

The aviator and balloonist may also experience blood compensations. Studies during a flight are difficult to make and subject to the criticism that the wind causes such rapid evaporation of the freshly drawn blood that an increased count may be attributed to its action. Gaule (39), Gemelli (40), and Culpepper (19) report increases in the erythrocytes and hemoglobin during flights; and the last two authorities hold that repeated ascents will give a permanent increase. They advance the opinion that cold is the main cause. A rapid increase in the absence of cold has been demonstrated by means of the low-pressure chamber and under low oxygen at normal atmospheric pressure by Gregg, Lutz, and Schneider (42). They and Haldane, Kellas, and Kennaway (49) fail to find a lasting effect from brief exposure to low-oxygen tensions.

RATE AND TIME OF CHANGE.

To determine the rate at which these blood changes take place during residence at a high altitude necessitates making allowance for the diurnal variations. Dreyer, Bazett, and Pierce (25) have shown that the daily variations in the per cent of hemoglobin in man and animals are large, changes of 10 per cent are more or less common, and may even reach as much as 30 per cent. The diurnal curve shows two maxima between 4 and 8 a. m. and p. m. and two minima between 10 and 1 o'clock night and day. If the literature on altitude blood changes be examined with this curve some of the disagreement between investigators can be accounted for.

The time required for the altitude blood changes to become evident appears to be determined by the rate and height of the ascent and the physical condition of the subject and, to some extent, by the amount of physical effort made. Gregg, Lutz, and Schneider (42) with the low-pressure chamber and low oxygen at normal atmospheric pressure observed that, when the oxygen tension was lowered at a rate comparable to ascending 1,000 feet per minute, to pressures corresponding to 15,000 to 18,000 feet, the erythrocytes and hemoglobin increased in 78 per cent of all men examined. In some of the men the increase began within 26 minutes and in the majority between 40 and 60 minutes.

The mountaineer, whether going afoot, by railway, or automobile, ascends more slowly than the aviator; consequently the blood changes appear much later. Douglas, Haldane, Henderson, and Schneider (23) observed in themselves, several hours after reaching the summit of Pikes Peak, a slight increase in hemoglobin that did not reach 3 per cent in any case. Work with animals has revealed an increase within a few hours (16), (20). Schneider and Havens (82) had under observation healthy young men who ascended passively by railway and showed no response during the first 7 hours at an altitude of 14,110 feet. The usual response during residence at a high altitude consists of a rapid increase in the number of erythrocytes and percentage of hemoglobin during the first two to four days, followed by a more gradual increase that requires several weeks and even months to establish equilibrium. Individual differences are always observed when a group of men is considered, as in the Anglo-American and the Bürker expeditions. A splendid set of observations that gives the typical curve is that of Richards (74) on himself, at 15,000 feet, in Bolivia. In five days his hemoglobin increased from an average of 101 to 129 per cent on the Gower–Haldane scale, and then rose very gradually for two and one-half months to 146. A residence of a few days to a week at the high altitude is not sufficient time for the changes to be completed. Schneider and Havens (82) observed two men who failed to respond in four days and others in whom the first changes were delayed one and two days. The men who were tardy in making these blood changes were fatigued by ascending on foot or were not in the pink of condition. The Anglo-American Pikes Peak expedition noted a distinctly low hemoglobin in three of the party the day following a fatiguing climb.

THEORIES ON THE MECHANISM OF ADJUSTMENT.

Among the theories advanced to account for the increase in the erythrocytes and hemoglobin are (*a*) an increased concentration of the blood; (*b*) increased hematopoietic activity of the bone marrow; (*c*) the existence of a reserve or dormant supply of ertyhrocytes; (*d*) a lengthening of the life of the erythrocytes (for which there has been no experimental evidence); and (*e*) an unequal distribution of the red corpuscles.

Grawitz (41) early maintained that as a result of increased evaporation of water from the body the blood becomes more concentrated at high altitudes. Weiss (101) was unable to detect any alteration in the amount of hemoglobin per kilo body weight in animals at 4,000 feet, even though the number of erythrocytes per cubic millimeter was increased. Jaquet (57), on the other hand, found in animals kept under a barometric pressure of 640 millimeters of Hg. (5,000 feet) that not only the percentage of the hemoglobin but also the total mass of hemoglobin increased, while the volume of blood remained practically unaltered. Abderhalden (1), working with animals at 6,100 feet, concluded that the amount of hemoglobin per animal was not altered, although the amount per kilo body weight as well as the percentage value of the hemoglobin and red corpuscles rose. The weight of his animals was uniformly less at the high altitude. He took this to indicate a concentration of the blood without overproduction. Dreyer and Walker (24) believe that the change in blood volume is proportional to the area of the body surface. They recalculated Abderhalden's data and found that while the animals showed a diminished blood volume, yet the total amount of hemoglobin indicated a new formation; but they concluded that in animals examined during the first day or two after ascent the whole change was due to a

diminution in the blood volume. Douglas, Haldane, Henderson, and Schneider, by the carbon monoxide method of Haldane and Smith (46), determined the total amount of hemoglobin and the blood volume of four men during a residence of five weeks on Pikes Peak. They are of the opinion that three of their subjects had a diminished blood volume during the first days, but that afterwards there was a large increase in the total amount of hemoglobin and a return to, or even a slight increase above, the normal volume.

Other evidence of increased activity of the hematopoietic tissue has been forthcoming. Thus Zuntz, Loewy, Müller, and Caspari (104), by a histological study of the bone marrow of dogs at sea level and at a high altitude, showed a decrease in fat cells and an increase in the blood-forming elements in the animals acclimated to the high altitude. Dallwig, Kolls, and Loevenhart (20) found an extension of the red marrow in animals under low oxygen, and a large increase of hemoglobin per kilo body weight. Laquer (63), working with dogs, found that if they were deprived of hemoglobin by a hemorrhage of half their blood supply, at sea level 27 days and on Monte Rosa 16 days were required to regenerate the hemoglobin. Schneider (78) proved there had been overproduction of red corpuscles and hemoglobin by determining the changes after descent in a man who had lived 6 months at an altitude of 14,000 feet. In the course of 10 weeks the total oxygen capacity of the blood decreased about 12 per cent.

Schneider and Havens (82), from observations on the effects of abdominal massage and muscular exertion, concluded that a part of the first increase in red corpuscles and hemoglobin occurring with residence at a high altitude was brought about by the passage into the general circulation of a large number of red corpuscles that ordinarily are stored away. Their reasons were as follows: At low altitudes abdominal massage and physical exertion increase the number of erythrocytes and percentage of hemoglobin in the peripheral capillaries; at high altitudes, before the blood changes of acclimatization have appeared, these still raise the content of hemoglobin and red corpuscle; but after men are partially or wholly acclimatized abdominal massage and exercise lower instead of increase their content. Recent work on the regulation of the volume and concentration of the blood has not favored this explanation. Scott (86) was unable to find masses of corpuscles stored away anywhere in the body and believes that the capillary blood is the same as that in the large vessels. Scott, Herrman, and Snell (87) found an increase of the water content of the muscles during contraction and concomitantly with this an increased hemoglobin content and blood count. This passage of water out of the blood was associated with a rise in blood pressure. Lamson (64) also was unable to find a reservoir of red corpuscles of sufficient magnitude to appreciably influence the red count. He finds that all conditions of acute polycythemia in which there has not been sufficient time for red cell production are due to concentration of the blood by fluid loss, and that this loss from the circulation occurs through the liver lymphatics. While these more recent studies throw doubt on the explanation offered by Schneider and Havens, they do not account for the fact that after acclimatization abdominal massage and physical exertion not only failed to cause the usual concentration of the blood, but actually caused a decrease in the content of hemoglobin and the red cell count.

The mechanism by means of which the blood is concentrated has not been carefully considered with respect to altitude and low oxygen. That it is not chiefly the result of evaporation of water from the body as suggested by Grawitz is evident from the observation of Dallwig, Kolls, and Loevenhart and of Gregg, Lutz, and Schneider, in which men and animals were held under such conditions that perspiration and evaporation were normal or subnormal; furthermore Gregg, Lutz, and Schneider obtained concentration within 15 to 20 minutes without any noticeable increase in the activity of sweat glands. Against the theory that it is chiefly due to an increased activity of the kidneys, as suggested by Birley (12) from observations on aviators, Gregg, Lutz, and Schneider urge that the time in which concentration occurs, 15 or 20 minutes as seen in some aviators, is too short and the volume of urine eliminated too small. A study of the weight of subjects before and after experiment proves conclusively that the concentration can not be due to a loss of water from the body. That it is not associated with the blood pressure is evident from numerous mountain, low-pressure chamber, and rebreathing experiments in which the arterial pressures have not increased, but in some instances have decreased as the blood concentrated. The work of Bogert, Underhill, and Mendel (13) and Scott, Herrman, and Snell (87) show that in the regulation of blood volume the tissues act as the reservoir for excess fluid. Furthermore, as shown by Smith and Mendel (90), the excess of fluid may leave the blood as an exudate into the serous cavities or be excreted into the intestine and stomach.

The theory that the blood changes of altitude are due to an alteration in the distribution of the erythrocytes has had its chief support from Foa (34), who found that the ear veins of rabbits contained more red cells than the blood from an artery; and from Campbell and Hoagland (16), who found the blood from the mesenteries poorer in erythrocytes than that from the ear. Dallwig, Kolls, and Loevenhart (20) later examined blood from the marginal ear vein and the carotid artery and heart and found the counts were the same within the limits of experimental error.

Undoubtedly the increase in hemoglobin observed, during short exposures to and during the early days at high altitudes, is largely or wholly due to a loss of fluid from the blood; while the permanent condition of acclimatization is the result of a new formation of red cells which finally restores the blood volume to normal.

Reasoning from the fact that his own erythrocytes did not increase during a short visit to Leadville and Pikes Peak at a time when his red count was abnormally high at sea level, Sundstroem (93) concludes that health in high altitudes is compatible with numbers of red cells that are normal for low elevations. The opinion is not in accord with some able clinicians. Sewall (76) considers anemia a dominant disorder at altitudes of 5,000 and 6,000 feet. He finds that failure to react normally to the altitude leaves the body in a mild grade of altitude anemia that originates or accelerates many functional disorders. Moleen (69) also finds much of the so-called altitude nervousness due to the failure of the hematopoitic response and that, if by therapeutic or other means the

blood-forming mechanism can be stimulated into activity, individuals find no difficulty in living tranquil lives at high altitudes.

Variation in the size of the erythrocytes has been considered. Koeppe (59) found a decrease while Schauman and Rosenqvist (77) report a progressive increase in the diameter at high elevations. Sundstroem (92), (93) observed that in the same person on different occasions there may be either an increase or decrease in the diameter and suggests that these alterations may be caused by, or correlated with, changes in the acid-base equilibrium of the blood.

Numerous attempts have been made to find nucleated red corpuscles but many have been futile. Schauman and Rosenqvist in experiments on animals found an increase of normoblasts and free nuclei. Gaule (39) from balloon ascensions gives doubtful descriptions of nucleated red cells and Sundstroem after much searching of his own blood found two characteristic normoblasts and a few free nuclei. Dallwig, Kolls, and Loevenhart (20), working with animals kept under a low percentage of oxygen, showed that the number of basophilic erythrocytes was increased and that many of these were abnormally large. Such cells are indicative of excessive activity of the hematopoietic tissue.

LEUCOCYTES AND PLATELETS.

The number of white corpuscles is approximately the same at all altitudes (91), (92), but the differential count reveals a difference in the kinds of leucocytes. The outstanding feature is an increase in the large lymphocytes. The number of polymorphonuclear cells diminishes in exact proportion in which the mononuclear cells increase (91), (92), (99).

Comparatively little work has been done in connection with the blood platelets. Kemp (58) in 1903 found a tremendous increase at 14,000 feet. Webb, Gilbert, and Havens (100) found that the platelet count at sea level as obtained from an average of counts made on 100 college students was 302,000, and for 100 men at 6,000 feet was 340,000 per c. mm. No reason is known for this increase.

THE HEMATO-RESPIRATORY FUNCTIONS AT HIGH ALTITUDES.

The whole problem of respiration at high altitudes is very closely linked with the control of the chemical reaction of the blood and therefore with the explanation of acidosis. Our interest centers about the balance of acids and alkalies because the absorption and unloading of oxygen by the blood is altered by variations in these. Carbon dioxide, by virtue of its acidic character, affects not only the respiratory center but also the dissociation of oxyhemoglobin; an increase in the partial pressure of carbon dioxide augments the dissociation, while a decrease causes the hemoglobin to hold more tightly to its oxygen.

It was early noted that the volume of air breathed is increased at high altitudes, while the alveolar carbon dioxide pressure is lower than at sea level. To account for this increase in breathing Zuntz and associates (104) and Haldane and collaborators (14), (48), (98) developed a theory that still persists, to a degree, among physiologists today; namely, that a deficiency of oxygen produces acids that are added to the blood. Boycott and Haldane (14) believed that the hyperpnea observed under want of oxygen is due to the formation of lactic or other acid substances and that these have the same influence as carbon dioxide on the respiratory center, so that less carbon dioxide is required to excite the center. That lactic acid does not accumulate in the blood, at least at moderately high altitudes, was proven by Barcroft, Camis, Mathison, Roberts, and Ryffel (7), (8) in their expedition to Mount Rosa.

Studies of the dissociation curve of the blood by Barcroft (7) and the Anglo-American Pikes Peak Expedition (23) have shown that, in the acclimated individual, the affinity of hemoglobin for oxygen is the same as at sea level, if the blood be exposed to a carbon dioxide pressure characteristic for the alveolar pressure of the altitude. This indicates that the carbon dioxide has been displaced by something which produces an equal effect on the affinity of hemoglobin for oxygen. If the blood of an altitude acclimated person be exposed to 40 millimeters of carbon dioxide, the average alveolar carbon dioxide at sea level, the dissociation curve is displaced to the right, thus proving there has been an increase in acid radicals or a decrease in the bases of the blood. To account for these changes Douglas, Haldane, Henderson, and Schneider suggested the theory that the adaptive regulation of the blood alkalinity is accomplished by a slight and gradual alteration in the exciting threshold of alkalinity for the kidneys, whereby they would slowly reduce the alkalinity of the blood and restore the acid-base relationship to that characteristic of acclimated persons. The stimulus for the slight alteration was assumed to be the presence of abnormal quantities of metabolites in the blood which had escaped oxidation in the lungs. This theory has recently been modified by Haldane (45) in view of more extended observations.

Y. Henderson and Haggard (44), (54) have used the carbon dioxide dissociation curve of the blood to show the amount of alkali in use in the blood. They find, with oxygen deficiency, that augmented breathing begins before a reduction of the blood alkali occurs, and that there is not a lowering of the blood alkali before or coincident with the increase in breathing, as was formerly taught. They find the hemato-respiratory events of acclimatization occur in the following order: 1, a lowering of the oxygen tension of the inspired air; 2, a stimulation of the respiratory center or, as they state it, an increased production of respiratory x; 3, excessive respiration and a blowing off of carbon dioxide; 4, a decrease in the ratio of H_2CO_3: $NaHCO_3$, which means a lowering of the hydrogen ions, an alkalosis of the blood instead of the acidosis of earlier theories; and 5, a compensatory disappearance of alkali from the blood. In complete acclimatization to any altitude the volume of air breathed is in inverse proportion to the amount of alkali in the arterial blood. Unquestionably the oxygen tensions in the lungs and arterial blood give the condition to which the organism adjusts its respiratory activity.

Haldane (45) explains these hemato-respiratory changes of acclimatization as follows: The hydrogen ion concentration of the blood is regulated with great delicacy by the respiration on the one hand and the kidneys and the liver on the other, the respiration doing the rough and immediate work by increasing or decreasing the elimination of carbon dioxide, and the kidneys the finer and slower work by adjusting fixed alkalies and acids. Oxygen want serves as an additional stimulus to the respiratory center, causing

an increased amount of carbon dioxide to be washed out of the arterial blood. This loss of carbon dioxide makes the blood abnormally alkaline and causes the kidneys and liver to slowly redress the balance, the kidneys by excreting the excess of alkali and the liver by suppressing the accumulation of free ammonia.

The evidence in favor of the latest theory is the work of a number of laboratories. That the respiratory center is directly stimulated by oxygen deficiency is indicated by experiments of Gasser and Loevenhart (38) on animals and Lutz and Schneider (66) on men, in which they find that the hyperpnea may be excited by want of oxygen within 4 to 35 seconds, average about 14.5 seconds; a time too brief to make it probable that the stimulation is due to the accumulation of metabolites in the blood or the respiratory center. Haldane, Kellas, and Kennaway (49) also conclude that oxygen deficiency *per se* can act as a stimulus to the respiratory center.

That there occurs increased breathing and a blowing off of carbon dioxide is clear from the alveolar air studies cited under our discussion of respiration. Theoretically the alveolar carbon dioxide is proportional to the carbon dioxide content of the blood. In addition direct measurements of the carbon dioxide content by Paul Bert (10) and Mosso and Marro (71) on dogs and by Sundstroem (92), by Van Slyke's method on himself, confirm the opinion that low oxygen tensions cause a loss of carbon dioxide from the blood.

In 1918, by simultaneous determination of carbon dioxide content and carbon dioxide capacity (which is a measure of the alkalinity) of the blood, Y. Henderson and Haggard (55) have shown that a decrease of the former is followed by a decrease in the latter, but that a lagging behind of the carbon dioxide capacity may occur. In a later paper they cite experiments made upon men by this method by Lutz and Schneider (44), in which the blood alkali during periods from 60 to 90 minutes of oxygen deficiency was not reduced, even though the carbon dioxide was reduced and the normal ratio H_2CO_3: $NaHCO_3$ was changed in the direction of a temporary alkalosis. Sundstroem (92), during the first two days of a sojourn at 14,110 feet, found the urinary excretion of base much less than later, while the hydrogen ion determination of the blood indicated an alkalosis.

That later the kidneys and liver restore the hydrogen ion content of the blood has been proven in several ways. Hasselbalch and Lindhard (53) found that the H-ions of the urine were reduced for several days and returned to normal only after acclimatization was established, and that the excretion of ammonia was also relatively decreased and continued somewhat low even after acclimatization. This latter condition Haldane (49) considers an evidence of a slight continuous alkalosis. By carefully constructing balance sheets of all the acid and basic elements in the food, feces, and urine, and thus obtaining the total acid-base balance of the body at low and high altitudes, Sundstroem (92) at high altitudes found an increased output of base which consisted largely of fixed alkalies. He also obtained a decrease in the ammonia output which he explained as a corollary to the increased elimination of fixed alkalies. In this connection it should be noted that Macleod (67) has suggested that an excess of lactic acid in anoxemia may perform the function of neutralizing the relatively increased base. Sundstroem, however, found that excretion of lactic acid did not increase. Haldane, Kellas, and Kennaway (49) have shown that the titrable acids, as well as the ammonia, of the urine are much reduced during exposure to oxygen deficiency. These observations clearly indicate that it is the function of the liver and kidneys to restore the H-ion content of the blood resulting from the loss of carbon dioxide, and thus to give the final hemato-respiratory equilibrium of acclimatization. It is also evident that the total alkalinity, the alkaline reserve, is reduced in inhabitants of high altitudes.

There is a lack of agreement as to what maintains the greater ventilation of the lungs and the low alveolar carbon dioxide after acclimatization. Barcroft (7) found that at any altitude, the acidosis and diminution of carbon dioxide so nearly balance one another that the reaction of the blood remains practically constant; and yet he has been able to show by a statistical study that there was a slight increase in acid over the sea-level amount, and this he considered sufficient to give the respiratory center the slight stimulation which would account for the altitude increase in lung ventilation. Sundstroem, by an indicator method, finds a slight acidosis of the blood after successful acclimatization that lends support to Barcroft's position.

Hasselbalch and Lindhard (53) give a different interpretation. They find in acclimatization that the H-ion concentration of the blood is the same at all altitudes, and hold that the primary change is in the respiratory center, which becomes abnormally sensitive to the H-ions, resulting in increased breathing.

Haldane (45) is of the opinion that while after acclimatization the H-ions are again probably nearly the same as at sea level, yet the restoration is never quite complete; so in the end there continues a slight alkalosis which gives evidence of a continued though slight oxygen want, and it is this that still permits action of diminished oxygen on the respiratory center. Henderson (44) believes that it is a low oxygen to alkali ratio that tends to stimulate respiration. Or rather, it is the low oxygen—alkali ratio—which produces the respiratory x, that stimulates the respiratory center. He declares that it is not enough to say that oxygen deficiency is itself a stimulus or that it governs the excitability of the respiratory center for carbon dioxide, as these leave the question of how it does this unanswered. He therefore postulates an unknown substance, labeled respiratory x, that is formed by the action of the oxygen—alkali ratio.

During the early stages of adjustment to the low oxygen tension of high altitudes, the condition in the blood is favorable to a serious oxygen want. The loss of carbon dioxide from the blood should mean an increased affinity for oxygen. When the blood is in the lungs this would lead to a better absorption of oxygen than normally. However, when the blood is in the systemic capillaries the opposite is the case, and this same affinity then prevents as free a passage of oxygen outward from the blood as normally would occur at lower altitudes. Therefore, until the liver and kidneys overcome the alkalosis of the blood, the tissues of the organism suffer an oxygen want to a greater degree than they will later. The restoration of the normal hydrogen-ion content of the blood, in that it restores the oxyhemoglobin dissociation curve to about its sea-level value, must be regarded as an important factor in acclimatization.

MOUNTAIN SICKNESS.

The aviator, as has been previously pointed out, does not suffer from mountain sickness but simply from oxygen want. The degree appears to be determined chiefly by two factors, namely, the partial pressure of oxygen in the alveolar air of the lungs and blood, and by the degree of alkalosis of the blood. The latter as shown above affects the oxyhemoglobin dissociation by preventing the normal dissociation of oxygen and thus decreases the amount that passes to the tissues. The effects, as indicated by the recorded symptoms, appear to be chiefly caused by want of oxygen in the brain.

A complete explanation of mountain sickness has not yet been given. Without doubt it is chiefly due to anoxemia, so that such of the older theories as attribute it to mechanical causes and to the absence of carbon dioxide may be here neglected. Barcroft (7) believes that mountain sickness is caused by want of oxygen on the brain itself, but that the vomiting center is stimulated by the lack of acid in the blood. He points out that the symptoms of mountain sickness resemble those of a hemorrhage. As a preventive, he urges that acids be courted by physical exercise.

Y. Henderson and Haggard (44) believe that their postulated respiratory x may cause the symptoms of mountain sickness, in that it at first acts very much like ethyl ether in the excitement stage; while its later effects resemble the disagreeable manifestations of alcoholic intoxication.

Haldane, Kellas, and Kennaway are unable to say to what extent mountain sickness is due to anoxemia or to the secondary diminution of the H-ions of the blood (alkalosis), but they believe the two causes are closely bound up together. Sundstroem states that it is possible that mountain sickness can be directly explained as a failure of the kidneys to respond sufficiently quickly to the excess of bases in the blood. He found an alkalosis of the blood during his attack of mountain sickness, and a normal H-ion concentration in the afternoon of the same day, when the symptoms of mountain sickness had entirely disappeared. Haldane, Kellas, and Kennaway are of the opinion that good toleration of high altitudes is dependent upon the ability to quickly eliminate the excess of blood alkalies. The observations of Mosso (71) and of Hasselbalch and Lindhard (53) that the symptoms of mountain sickness were reduced by the inhalation of proper dilutions of carbon dioxide, and Barcroft's suggestion of courting acid, find a satisfactory explanation in the theory that alkalosis is at least a secondary cause of the symptoms of mountain sickness.

THE CIRCULATORY MECHANISM AT HIGH ALTITUDES.

THE HEART RATE.

The response of the heart to oxygen deficiency gives a good illustration of the fact that the behavior depends upon the suddenness and the extent of the changes in oxygen. Lutz and Schneider (66) by having men inspire nitrogen, obtained an acceleration of the heart in from 5 to 55 seconds, in 66 per cent of all cases within 15 seconds or less. In a low pressure chamber, in which the barometric pressure was lowered at a rate corresponding to an ascent of 1,000 feet a minute, 26 per cent of all cases showed an increase at tensions of oxygen equivalent to an altitude of 4,000 feet or less. In airplane flights the psychic influence of the excitement of taking off usually obscures the beginning of the low oxygen effect, but Hodgson (56) has recorded several flights to 16,000 feet in which the typical low oxygen action is well illustrated. The experiments of Lutz and Schneider and the statistical study of Schneider and Truesdell (85) show that the heart rate slowly and gradually increases until the oxygen tension is about that of 14,000 feet, and from there on the increase is by much greater increments for each thousand feet of ascent. The increase averaged 15 beats at 15,000 feet and 20 at 18,000 feet.

Schneider (79), Lutz and Schneider (66) and Haldane, Kellas, and Kennaway (49) observed that, if a constant level of low oxygen be maintained for an hour or more, the rate in may cases again retards, although in some there is a continued augmentation during the entire time of maintained level.

In the slow ascent of mountains which is followed by a sojourn of weeks or months the story is different. The early literature has been reviewed by Durig and Kolmer (26) and Schneider and Sisco (83). If the ascent be made passively by railway to 14,000 feet there is, as a rule, no acceleration during the ascent. What happens later appears to depend on the physical condition of the subject. If he compensate well to the altitude, his pulse rate, at rest, will not show an increase for some hours; but by the next morning the rate, while in bed, will be slightly accelerated and continue to show a further increase each morning for from three to five days. In those less tolerant to altitude the heart accelerates as the attack of mountain sickness comes on, so the early morning rate may reach its maximum by the first morning. As the attack passes off the heart retards. In men who climb the mountain on foot or on a burro or horse, the fatigue of the climb causes the pulse rate to resemble that in mountain sickness. The greatest augmentation occurs in men physically weak. The daily variations in pulse rate show the same proportionate increase as the early morning rate when compared with similar conditions at lower altitudes. While a number of authors have thought the pulse extraordinarily labile at high altitudes, Schneider, Sisco and Cheley (84) did not find it necessarily so. The heart works at an increased rate in all postures at high altitudes, with about the same differences as at the low altitude. The amount of increase, of course, differs with individuals; some show, at 14,000 feet, an augmentation of only a few beats, while others increase 10 or more over the low altitude rate.

During a prolonged sojourn at a high altitude the heart rate may show a gradual daily increase for about a week or two, but as other adaptive changes reach their maximum efficiency there is a tendency to return toward the low altitude rate (23). In only rare cases does it completely return to the low altitude normal.

The "after effects" of a visit to a high altitude differ from those observed for respiration. After an exposure to oxygen deficiency for an hour or so the heart returns at once to its normal rate, but if the stay has been long enough for the permanent changes of acclimatization then the return to a low altitude may be followed by a subnormal rate. Durig and Kolmer (26), Schneider (78) and others (52), (92) have found a subnormal period that

lasts many days. All observers agree that up to altitudes of 8,000 or 9,500 feet the acclimatized inhabitants do not show an altitude augmentation in heart rate.

THE ARTERIAL PRESSURES.

The circulatory responses to oxygen deficiency as experienced during the short exposures in aviation have been the subject of a number of papers from Medical Research Laboratory of the Air Service of the Army (79), (66), (43), (64), (85). In a rapid ascent to 15,000 or 20,000 feet, if the psychic factor be not active, the systolic pressure in a good compensation remains unchanged or shows a slight gradual rise of not more than 10 or 15 millimeters. The diastolic pressure is also maintained to oxygen tensions corresponding to 15,000 feet and thereafter, as higher altitudes are attained, slowly decreases by about 8 to 10 millimeters. If the compensations to the low oxygen be inadequate the aviator is liable to develop a fainting circulatory reaction of which a rapid fall in the systolic and diastolic pressures gives evidence of the oncoming syncope. The various types of circulatory reaction have been described in detail by Schneider and Truesdell (85).

The arterial blood pressures of people living in the mountains have been made a frequent subject of study. The early literature has been reviewed by Schneider and Hedblom (81) and Durig and Kolmer (26). The conclusions of the Anglo-American Pikes Peak Expedition (23) and of Schneider and Sisco (83), who have examined a goodly number of men, are that the altitude effects in those who ascend the mountain passively are so slight that they fall for the most part within the errors of observation. In the majority of healthy men at 14,110 feet the arterial pressures were normal for them; in some there occurred a slight fall and in a few a slight rise. However, during an attack of mountain sickness and in some cases during the first days of inadequate compensation both the systolic and diastolic pressures are above normal.

VENOUS AND CAPILLARY PRESSURES.

These pressures have not received much attention in anoxemia. Under the acute conditions of rebreathing and low-pressure chamber experiments of from 25 to 45 minutes' duration, the low oxygen reduced the venous pressure (80). On Pikes Peak, Schneider and Sisco found a lower venous pressure than at low altitudes. A few capillary pressure determinations with Lombard's device indicated that this pressure was slightly lower on Pikes Peak.

VOLUME OF BLOOD FLOW.

This subject has been difficult to approach because of the lack of a satisfactory direct method of determining the per minute output of the heart. The Anglo-American Pikes Peak Expedition concluded, from observations by means of a recoil board and from the pulse pressure, that the volume of the heart strokes continued practically the same on Pikes Peak as under ordinary barometric pressure. In one man, however, the heart stroke appeared to be somewhat diminished. The volume of the blood stream per minute in one subject was decidedly decreased in another unchanged, and in two others somewhat increased. Schneider and Sisco's records show that the pulse pressure averages slightly less on Pikes Peak, but that with two exceptions the difference is too small (2 millimeters) to be significant. They believe that their recoil board records, along with those of pulse pressure, indicate that in four men the output per heart stroke was the same at both altitudes, but in another was reduced at the high altitude. Using Stewart's method of measuring the amount of blood flow through the hand, by determining the amount of heat given off in a water calorimeter, they found the circulation rate through the hands was for six subjects from 30 to 76 per cent greater on Pikes Peak. These observations, supplemented by those of the recoil board and pulse pressure and the fact that the pulse rate had augmented. led them to conclude that the circulation rate as a whole was more rapid. Bainbridge (5) has pointed out that this increase in blood flow through the hands may be due to a dilatation of the limb vessels counterbalanced by vasoconstriction elsewhere, presumably in the splanchnic area.

Hasselbalch and Lindhard (53), in six experiments in a low-pressure chamber, at a barometric pressure somewhat under 12,000 feet, using a respiratory nitrous oxide method developed by Krogh and Lindhard, found a slight increase in the output of the heart in three of the tests. The fact that this increase was slight and that the flow was unaltered in the other experimenets led them to conclude that the output of the heart is not increased at high altitudes during rest.

Kuhn (61), using the respiratory method of Plesch at an altitude of 11,000 feet, found that the output per heart stroke was decreased in two, unchanged in one, and increased in the fourth man; while the per minute volume output of the heart was somewhat augmented in each subject (3.2, 5.8, 8.3, and 28.1 per cent).

Lutz and Schneider (66) find, in low pressure chamber experiments, indications of an increased blood flow in the augmentation in the rate of heart and in changes in the arterial pressures, which result in an increase in the pulse pressure. They also find that, when a constant level of oxygen is maintained, the heart rate may diminish and the pulse pressure again decrease. The interplay of the various circulatory factors throughout their experiments seems to support the theory of an increased blood flow during anoxemia.

That the volume of blood passing through the lungs during acute anoxemia, in an anesthetized cat, was the same as under ordinary atmospheric air has recently been demonstrated by Doi (105), by the use of a method in which the oxygen consumption per minute and the oxygen content of arterial and venous blood were determined. From the minute volume thus obtained he calculated that the output of each heart beat had decreased. Doi's findings are by means of a more direct method than others reported above and make it appear that the acceleration of the heart in anoxemia is a symptom of distress and not of compensation. This problem of the volume of the blood stream from the heart needs further study by these more direct methods under more natural conditions than obtain in the use of anesthetics. To the writer it does not seem likely that the acceleration of the heart which appears at the same time as the respiratory changes, in acute anoxemia, is merely a distress symptom.

EXERCISE.

Physical exertion makes greater demands on the heart and blood vessels at very high than low altitudes. Just at what altitude this begins has not been investigated. Schneider, Cheley, and Sisco (84) found that the arterial pressures were higher after a given form of work at the high than at the low altitude and that the influence of lowered barometric pressure was the more pronounced the more vigorous the exertion. The increased reaction to exercise was most conspicuous during the first days of residence. While the effects were lessened by acclimatization for moderate exertion, they did not show improvement in strenuous exercise. The systolic pressure after short quick runs was as high as during a maximum lift of weights. Further evidence of greater exercise demand on the heart was that the delay in the return to normal was as prolonged as after exhaustive exercises. In physically-fit men the influence of altitude in exercise was less.

Clinicians have found that as a rule the danger to the heart in high altitudes is overstrain from exercise and is not specifically due to altitude. Schrumpt (85) finds that up to 7,000 feet pathological blood pressures are improved. Zederbaum (103), Wyss (102), and others point out a fear of altitude among the laity and even medical men that is unwarranted, and show that altitudes up to 6,000 or 7,000 feet benefit many forms of heart disease.

Accepting then, for the present, only such factors as have been clearly demonstrated to serve in the compensation to anoxemia, we may rank them as follows: 1, increased respiration; 2, chemical alterations in the blood; and 3, increased hemoglobin. The respiratory change ranks first because by this means the partial pressure of the oxygen in the lungs is raised above what it would normally be at the altitude. This favors not only the absorption of oxygen in the lungs, but also, after acclimatization, the passage of oxygen from the blood to the tissues. Since the alkalosis resulting from augmented breathing interferes with the passage of oxygen from the blood to the tissues, it can not be questioned but that the restoration of the normal H-ion content, by the elimination of the excess of alkali, constitutes a compensatory process of almost if not equal importance with the increase in breathing. The advantage gained by the increase in hemoglobin is not so obvious. Barcroft (6) finds the increase of but little value, since even if it be sufficient to restore to normal the actual quantity of oxygen in 1 cubic centimeter of blood then, because of the decrease in oxygen pressure, the rate of dissociation will be so slow that it will not allow the oxygen to pass to the tissues in anywhere near the same proportions. Haldane (49) considers the advantage of the increase in hemoglobin due to the fact that the partial pressure of oxygen in the blood of the systemic capillaries is prevented from falling as low as it otherwise would.

BIBLIOGRAPHY.

(1) Abderhalden, E.: Zeitschr. f. Biol., 1902, xliii, 125 and 443.

(2) Air Service Medical, Washington, 1919, 137.

(3) Aviation Medicine in the A. E. F., Washington, 192 59.

(4) Bagby, E.: Air Medical Service, Washington, 1920, i, March 46 and August, 16.

(5) Bainbridge, F. A.:Physiology of muscular exercise, London, 1919, 165.

(6) Barcroft, J.: Lancet, 1920, cxcix, ii, 485.

(7) Barcroft, J.: Respiratory function of the blood, Cambridge, 1914.

(8) Barcroft, J., Camis, M., Matihson, C. G., Roberts, F. and Ryffel, J. H.: Phil. Trans. Roy. Soc. London 1914, B, ccvi, 49.

(9) Barcroft, J., Cooke, A., Hartridge, H., and Parsons, T. R.: Journ. Physiol., 1920, liii, 450.

(10) Bert, P.: La pression barométrique, Paris, 1878.

(11) Bert, P.: Compt. rend. Acad. Sci., 1882, xciv, 805.

(12) Birley, J. L.: Repts. Air Med. Invest. Com., London, 1918, no. 2, 3.

(13) Bogert, L. J., Underhill, F. P., and Mendel, L. B.: Amer. Journ. Physiol., 1916, xli, 189.

(14) Boycott, A. E., and Haldane, J. S.: Journ. Physiol. 1908, xxxvii, 355.

(15) Bürker, K., Jooss, E., Moll, E., and Neumann, E. Zeitschr. f. Biol., 1913, lxi, 379.

(16) Campbell, W. A., and Hoagland, H. W.: American Journ. Med. Sci., 1901, cxxii, 654.

(17) Cohnheim, O.: Physiologie des Alpinismus, Ergebn. d. Physiol., 1903, ii, i, 612.

(18) Cohnheim, O.: Med. Klinik, 1913, xx, 783.

(19) Culpepper, W. L., Military Surgeon, 1921, xlviii, 180.

(20) Dallwig, H., Kolls, A. and Loevenhart, A. S.: Amer. Journ. Physiol., 1915., xxxix, 77.

(21) Douglas, C. G.: Journ. Physiol., 1910, xl, 454.

(22) Douglas, C. G., and Haldane, J. S.: Journ. Physiol., 1912, xliv, 305.

(23) Douglas, C. G., Haldane, J. S., Henderson, Y., and Schneider, E. C.: Phil. Trans. Roy. Soc., London, 1913, B, ciii, 185.

(24) Dreyer, G., and Walker, E. W. A.: Lancet, 1913, clxxv, 1175.

(25) Dreyer, G., Bazett, H. C., and Pierce, H. F.: Lancet, 1920, cxcix, ii, 558.

(26) Durig, A.: Physiologische Ergebnisse der im Jahr 1996 durchgeführten Monte Rosa Expedition, Wien, 1909.

(27) Durig, A., and Zuntz, N.: Biochem. Zeitschr., 1912, xxxix, 435.

(28) Durig, A., and Zuntz, N.: Arch, f. Physiol., 1914, Suppl., 417.

(29) Eggers, F.: Arch. f. exper. Path. u. Pharm., 1897, xxxix, 426.

(30) Ellis, M. M.: Amer. Journ. Physiol., 1919, l, 267.

(31) Fick, A.: Arch. f. d. gesammt Physiol., 1895, lx, 589.

(32) Fitzgerald, M. P.: Phil. Trans. Roy. Soc. London, 1913, B. ciii, 351.

(33) Fitzgerald, M. P.: Proc. Roy. Soc. 1914, B. lxxxviii, 248.

(34) Foa, C.: Laboratoire Scientifique International du Mont Rosa, Turin, 1904, i, 15.

(35) Fuchs, R. F.: Physick, Med. Soz., Erlangen, 1908, xl, 204.

(36) Fuchs, R. F., and Deimler, T.: Sitzber. Physick. Med. Soz., Erlangen, 1909, xli, 125.

(37) Fürth, O.: Probleme der Physiologischen und pathologischen Chemie, Leipzig, 1913, ii, 585.

(38) Gasser, H. S., and Loevenhart, A. S.: Journ. Pharm. Exper. Therap., 1913, v. 239.

(39) Gaule, J.: Arch. f. d. gesammt. Physiol., 1902, lxxxix, 119 and 142.
(40) Gemelli, A.: Arch., ital. de biol., 1918, lxvii, 197.
(41) Grawitz, E.: Berl. Klin. Wochenschr., 1895, xxxii, 713 and 740.
(42) Gregg, H. W., Lutz, B. R., and Schneider, E. C.: Amer. Journ. Physiol., 1919, 1, 216 and 302.
(43) Greene, C. W.: Amer. Journ. Physiol., 1919, xlix, 118.
(44) Haggard, H. W., and Henderson, Y.: Journ. Biol. Chem., 1919, xxxix, 163; 1920, xliii, 3 and 15.
(45) Haldane, J. S.: British Med., Journ., 1919, ii, 65.
(46) Haldane, J. S., and Smith, L.: Journ. Physiol., 1897, xxii, 232.
(47) Haldane, J. S. and Priestlye, J. G.: Journ. Physiol., 1905, xxxii, 25.
(48) Haldane, J. S., and Poulton, E. P.: Journ. Physiol., 1908, xxxvii, 390.
(49) Haldane, J. S., Kellas, A. S., and Kennaway, E. L.: Journ. Physiol., 1919, liii, 181.
(50) Hall, J. N.: Trans. Amer. Climat. Assoc., 1908, xxiv, 142.
(51) Hasselbalch, K. A.: Biochem. Zeitschr., 1916, lxxiv, 48.
(52) Hasselbalch, K. A., and Lindhard, J.: Skand, Arch. f. Physiol., 1911, xxv, 387.
(53) Hasselbalch, K. A., and Lindhard, J.: Biochem. Zeitschr., 1915, lxviii, 265 and 295; 1916, lxxiv. 1.
(54) Henderson, Y.: Journ. Biol. Chem., 1920, xliii, 29.
(55) Henderson, Y., and Haggard, H. W.: Journ. Biog. Chem., 1918, xxxiii, 333, 345, 355, and 365.
(56) Hodgson, J. E.: Journ. Roy. Army Med. Corps, 1919, xxxii, 473.
(57) Jaquet, A.: Arch. f. exper. u. Pharm., 1901, xlv. 1.
(58) Kemp. G. T.: Amer. Journ. Physiol., 1903, x, xxii.
(59) Koeppe, H.: Münch. med. Wochenschr., 1895, xlii, 880.
(60) Krogh, M.: Journ. Physiol., 1915, xlix, 271.
(61) Kuhn, H.: Über die Funktion des Herzens im Hochgebirge, Inaug. Dissert., Halle, 1913. Also Zentralbl. Physiol., 1913, xxvii, 1357.
(62) Lamson, P. D.: Journ. Pharm. Exper. Therap., 1920, xvi, 125.
(63) Laquer, F.: Deutsch. Arch. f. klin. Med., 1913, cx, 189.
(64) LeWald, L. T., and Turrell, G. H.: Amer. Journ. Roentg., 1920, vii, 67.
(65) Loewy, A., and Placzek, S.: Berl. klin. Wochenschr., 1914, li, 1017.
(66) Lutz, B. R., and Schneider, E. C.: Amer. Journ. Physiol., 1919, l. 228, 280, and 327.
(67) Macleod, J. J. R.: Amer. Journ. Physiol., 1921, lv, 175.
(68) Manual Med. Research Laboratory, Washington, 1918.
(69) Moleen, G. A.: Journ. Amer. Med. Assoc., 1916, lxvii, 477.
(70) Mosso, A.: Life of man on the high Alps, London, 1899.
(71) Mosso, A., and Marro, G.: Arch. ital. de biol., 1903, xxxix, 402.
(72) Muntz, A.: Compt. rend. Acad. Sc., 1891, cxii, 298.
(73) Oliver, G.: A contribution to the study of the blood and blood pressure, London, 1901.
(74) Richards, J.: Phil. Trans. Roy. Soc. London, 1913, B, ciii, 316.
(75) Ravenhill, T. H.: Journ. Trop. Med. Hyg., 1913, xvi, 313.
(76) Sewall, H.: Colo. Med., 1915, xii, 41.
(77) Schauman, O., and Rosenqvist, E.: Zeitschr. lkin. Med., 1898, xxxv, 162.
(78) Schneider, E. C.: Amer. Journ. Physiol., 1913, xxxii, 295.
(79) Schneider, E. C.: Journ. Amer. Med. Assoc., 1918, lxxi, 1384.
(80) Schneider, E. C.: Amer. Journ. Physiol., 1920, li, 180.
(81) Schneider, E. C., and Hedblom, C. A.: Amer. Journ. Physiol., 1908, xxiii, 90.
(82) Schneider, E. C., and Havens, L. C.: Amer. Journ. Physiol., 1915, xxxvi, 380.
(83) Schneider, E. C., and Sisco, D. L.: Amer. Journ. Physiol., 1914, xxxiv, 7 and 29.
(84) Schneider, E. C., Cheley, G. E., and Sisco, D. L.: Amer. Journ. Physiol., 1916, xl, 380.
(85) Schneider, E. C., and Truesdell, D.: Amer. Journ. Physiol., 1921, lv, 223.
(86) Scott, F. H.: Amer. Journ. Physiol., 1917, xliv, 298.
(87) Scott, F. H., Herrman, E., and Snell, A.: Amer. Journ. Physiol., 1917, xliv, 313.
(88) Strauch, A.: Amer. Jour. Med. Sci., 1911, cxlii, 105.
(89) Schrumpf, F.: Deutsch. Arch. f. klin. Med. 1914, cxiii, 466.
(90) Smith, A. H., and Mendel, L. B.: Amer. Journ. Physiol., 1920, liii, 323.
(91) Staines, M. E., James, T. L., and Rosenberg, C.: Arch. Int. Med., 1914, xiv, 376.
(92) Sundstroem, E. S.: Univ. Calif. Pub. in Physiol., 1919, v, 71, 87, 105, 113, 121, 133, 149, and 159.
(93) Sunderstroem, E. S., and Bloor, W. R.: Journ. Biol. Chem., 1920, xlv, 153.
(94) Viault, F.: Compt. rend. Acad. Sc., 1890, cxi, 917, and xciv, 1562.
(95) Viault, F.: Compt. rend. Soc. Biol., 1892, ix, Ser. iv, 569.
(96) VonVoornveld, H. J.: Arch. f.d.gesammt. Physiol., 1902, xcii, 1.
(97) Von Wendt, G.: Skand. Arch. f. Physiol., 1911, xxiv, 247.
(98) Ward, R. O.: Journ. Physiol., 1908, xxxvii, 378.
(99) Webb, G. B.: Phil. Trans. Roy. Soc. London, 1913, B, ciii, 312.
(100) Webb, G. B., Gilbert, G. B., and Havens, L. C.: Colo. Med., 1914, xi, 4.
(101) Weiss, J.: Zeitschr. f. Physiol. Chem., 1897, xxii, 526.
(102) Wyss, W. H.: Schweiz. med. Wochenschr., 1921, li, 36.
(103) Zederbaum, A.: Colo. Med., 1915, xii, 323.
(104) Zuntz, N., Loewy, A., Müller, F., and Caspari, W.: Höhenklima und Bergwanderungen, Berlin, 1906.
(105) Doi, Y.: Journ. Physiol., 1921, lv, 43.

—*By courtesy of Physiological Reviews.*

AVIATION MEDICINE.

AN OUTLINE OF THE PROGRESS IN RESEARCH AND TEACHING OF THIS SUBJECT IN THE UNITED STATES DURING THE CALENDAR YEAR 1921.

By L. H. Bauer, *Major, Medical Corps, United States Army, Commandant, Medical Research Laboratory and School for Flight Surgeons.*

During the past year progress in aviation medicine has been made in this country almost entirely by the personnel of the Medical Research Laboratory and School for Flight Surgeons and those formerly connected with it. In summarizing this subject it will be simpler, therefore, to take up the work of the various departments of the Medical Research Laboratory and School for Flight Surgeons and outline the publications issued and the research accomplished at that institution. In a paper of this sort it will be possible to give only a brief summary of the most recent articles and the recent research, and in the case of articles republished this year which have been published in previous years and which have been reviewed in other places, to refer only to the titles for the sake of completeness of bibliography. It will be convenient to consider this work under the following heads:

I. Research and publications:
   1. Aviation physiology.
   2. Aviation medicine.
   3. Neuro-psychiatry.
   4. Ophthalmology and otology.
   5. Aviation psychology.
   6. Miscellaneous.

II. Schools of instruction:
   1. Instruction for flight surgeons.
   2. Instruction for enlisted men.
   3. Library.

III. Routine work:
   1. Physical examinations.
   2. Branch laboratories.
   3. X-ray and photography.
   4. Personnel: (*a*) Officer; (*b*) Civilian.

IV. The future of aviation medicine.

1. RESEARCH AND PUBLICATIONS.

1. Aviation Physiology.

During the year there has appeared in various medical, scientific, and other journals a number of papers that embody the results of researches conducted by the Department of Aviation Physiology in the Medical Research Laboratory and School for Flight Surgeons. The titles of these papers, with the place and time of publication, were as follows:

"A Record of Experience with Certain Physical Efficiency and Low Oxygen Tests," by Edward C. Schneider. American Journal of the Medical Sciences, March, 1921, volume 161, pages 395–407.

"The Application of Certain Physical Efficiency Tests," by Verner T. Scott, Captain, M. C. The Journal of the American Medical Association, March 12, 1921, volume 76, pages 705–707.

"Pulse Rate and Blood-Pressure Responses of Men to Passive Postural Changes," by Max M. Ellis. American Journal of the Medical Sciences, April, 1921, volume 161, pages 568–578.

"A Study of Low Oxygen Effects during Rebreathing," by Edward C. Schneider and Dorothy Truesdell. American Journal of Psysiology, March, 1921, volume 55, pages 223–257. This subject was also published with additional data and discussion in the Air Medical Service Information Circular, July 15, 1921, volume 3, pages 6–25.

A paper that was first published in 1920 in the Journal of the American Medical Association, and that was widely reviewed in this country and abroad, was republished, on the request of the editors, in Mind and Body, March 1921, volume 27, pages 449–456. The title was "A Cardiovascular Rating as a Measure of Physical Fatigue and Efficiency," by Edward C. Schneider. The same paper with the exception of the introductory and historical paragraphs was also reprinted in the Journal of Industrial Hygiene.

All of the above-mentioned articles were reviewed in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920. In addition to these papers two more have been published. One of these was "A Study of the Influence of Various Circulatory Conditions on the Reaction to the Low Oxygen of Rebreathing," by Edward C. Schneider and Dorothy Truesdell, American Journal of Physiology, June, 1921, volume 56, pages 241–248. The same material with the addition of a larger amount of statistical data was discussed under the same title in Air Medical Service Information Circular, July 15, 1921, volume 3, pages 122–133.

In this research 10 special groups were selected from 2,000 cases for a study of the influence of various circulatory factors on the power of compensating to low oxygen under the conditions of our altitude classification rebreathing tests. The groups included high and low systolic pressures, high and low diastolic pressures, large and small pulse pressures, rapid and slow pulse rates, and cases of systolic pressure rise and fall on standing. A total of 554 cases were carefully examined and the mean or average reactions of each group determined. While each group was found to make the compensations to low oxygen in a similar manner and to tolerate equally low percentages of

oxygen, yet the plotted curves of the individual groups presented somewhat different pictures. The principal conclusion drawn was that none of the conditions studied appeared to place the heart and the nervous system under a handicap that is not present in average conditions of heart frequency and arterial blood pressures. It was shown that the rise in systolic pressure, at least under the conditions studied, is not great enough to place the heart under a dangerous strain.

The last paper published was "Physiological Effects of Altitude," by Edward C. Schneider, Physiological Reviews, October, 1921, volume 1, pages 631–659. This paper sums up the present-day opinions on the subject of the influence of high altitudes and low oxygen on mankind. In it are reviewed all of the experimental contributions of the last 15 years. The bibliography, which includes almost exclusively recent publications, includes 127 separate articles and books. It is the most complete paper yet written on the subject. After an explanation of anoxemia, the chief physiological factor of altitude, its effect on the aviator who experiences it for a short time, and on the mountaineer who through residence acclimates himself, Doctor Schneider discusses the respiratory response to altitude and the lowering of the CO_2 tension in the alveoli. He discusses the theory of O_2 secretion in the lungs and rejects it. He gives a careful explanation of the blood changes in acclimatization, the increase in hemoglobin, the effect of altitude on the H-ion concentration of the blood, and the mechanism by which this balance is maintained. He discusses the changes in the circulatory mechanism and the effect of physical exertion at high altitude and concludes as follows:

"Accepting then, for the present, only such factors as have been clearly demonstrated to serve in the compensation to anoxemia, we may rank them as follows: 1, increased respiration; 2, chemical alterations in the blood; and 3, increased hemoglobin. The respiratory change ranks first because by this means the partial pressure of the oxygen in the lungs is raised above what it would normally be at the altitude. This favors not only the absorption of oxygen in the lungs but also, after acclimatization, the passage of oxygen from the blood to the tissues. Since the alkalosis resulting from augmented breathing interferes with the passage of oxygen from the blood to the tissues, it can not be questioned but that the restoration of the normal H-ion content, by the elimination of the excess of alkali, constitutes a compensatory process of almost if not equal importance with the increase in breathing. The advantage gained by the increase in hemoglobin is not so obvious. Barcroft (six) finds the increase of but little value since even if it be sufficient to restore to normal the actual quantity of oxygen in 1 cc. of blood then, because of the decrease in oxygen pressure, the rate of dissociation will be so slow that it will not allow the oxygen to pass to the tissues in anywhere near the same proportions. Haldane (49) considers the advantage of the increase in hemoglobin due to the fact that the partial pressure of oxygen in the blood of the systemic capillaries is prevented from falling as low as it otherwise would."

There are now in press two articles that present physiological aspects of the work of the Medical Research Laboratory. Under the caption "The Human Machine in Aviation" the Yale Review will publish in nontechnical language descriptions of the physiological requisites of the the successful pilot, of the compensations the body is called upon to make during flying, and lastly of the apparatus and tests used in the laboratory. The second contribution that is soon to appear is a chapter on "Climatology." This will be in an important book edited by Doctor Barker, of the Johns Hopkins Medical School.

The fire which destroyed the old laboratory building and equipment not only interrupted the investigations of the department but also destroyed the original data of parts of researches that were in progress at that time. Fortunately considerable portions of original data and many summaries of results were in two desks that were only partly burned. Because of this a statistical study begun more than a year ago has been carried to completion, and the results are in manuscript form almost ready for publication.

The investigation deals with the pulse rate and the three arterial pressures—systolic, diastolic, and pulse pressure—under four conditions, viz, recumbency, standing, immediately after a standard exercise, and two minutes after exercise. The major part deals with observations on 2,000 men, but a second group of 200 more unselected cases, who were examined even more carefully, has been used to check the results obtained from the large group. In addition, a study was made of two small groups (144 and 204 cases) of men, judged by clinicians at the time of examinations to be physically fit. The data are discussed from the standpoint of the distribution of cases, the amount of postural and exercise change, time required to return to normal after exercise, and the interdependence of the several factors. To determine the extent that one circulatory factor may be dependent upon others, two methods of study were used. In the first, the coefficients of correlation and other statistical relationships were calculated, and in the second, a selection of groups of cases showing extreme and opposite conditions with repect to one factor have been examined as to the mean condition and reaction of all the other circulatory factors. Interesting tendencies and relationships have been established that add a new viewpoint to our knowledge of commonly observed circulatory factors. The summary of results is too long to incorporate in this report. One advantage gained from this investigation is the opportunity it offers to check the values used in the rating tables employed in the determination of physical fitness and staleness.

Several researches are now nearing completion:

(1) The anoxic effects of rebreathing and the low-pressure chamber have been studied on several circulatory factors and conditions not regularly considered in the altitude classification examination. In one series of runs venous pressure was taken by the Hooker method every minute. In another series capillary blood pressure was taken by means of the Danzer-Hooker microtonometer, readings being taken as often as possible throughout the runs, averaging about every three minutes. The subjects for this series were selected with great care, only those whose capillaries showed clear and unclouded readings being chosen. The rate of blood flow through the hands was also determined by the use of a Stuart calorimeter, readings being taken every minute before, during, and for several minutes after each run. The hand volume was determined by the use of hand plethysmograph. A rough estimate of the relative output of the heart was determined as evidenced by a recoil-board

curve or by the gaseous content of the blood and the lungs. After the completion of several more low-pressure chamber experiments these data will be prepared for publication.

(2) The influence of a gradual increase in the carbon dioxide of respired air has been studied with respect to the pulse rate, the arterial blood pressures, venous blood pressure, capillary blood pressure, hand volume, blood flow through the hand, the alveolar air composition, and the rate, depth, and per minute volume of breathing. These data are ready to be written up for publication.

(3) The cardiovascular rating scheme for physical fatigue and efficiency that has been in use in the Air Service for several years has been under special consideration. Attention was given to influence of the diurnal circulatory changes, observations having been taken on a group of subjects hourly for a period of 24 hours; to the influence of eating, of drinking, of smoking, of exercise, and of various mild pathological conditions.

(4) A series of observations on the effect of passive change of posture on pulse rate and the arterial pressures was made by use of the orientator, observations being taken to show the effect of the horizontal and the inverted positions, as well as the reactions after a series of about 10 loops. This study was begun in 1920 and carried over into 1921. The work is not yet complete.

(5) A series of experiments showing the effect of the inhalations of pure nitrogen, including observations on pulse rate, arterial pressures, hand volume with the use of the hand plethysmograph, and blood flow by the Hewlett method, as well as rate and volume of respiration. This method brought about a rapid and acute oxygen want effect, the runs averaging in length from 40 to 80 seconds.

(6) Experiments with dermographic tracings were continued both in routine examinations on subjects for the 609 examination and in experimental work to try the effects of different localities of the body, different temperatures, humidities, varying amounts of pressure, and the effects of wind. The work has not yet reached the stage where definite conclusious may be drawn, but it can safely be said that the conclusions drawn by former observers are unwarranted, as they have not given due weight to the various factors affecting dermographia.

Other problems are now partially under way. (1) The influence of excessive breathing, resulting in a washing of carbon dioxide from the body, is being compared with the effects of low oxygen and of carbon dioxide. The first part of study will be confined to the circulation and respiration. This will be followed by (2) a study of the chemical urinary and blood changes resulting during (*a*) overventilation of the lungs, (*b*) exposure to a gradually increasing amount of carbon dioxide, and (*c*) during the low oxygen effects of rebreathing.

Work has also begun on a study of metabolism during exposure to low barometric pressure in the low-pressure chamber. For this purpose, a series of Douglas bags are being used to collect the expired air for intervals of 10 minutes. By this method it may be possible to determine why the breathing increases not only during an ascent, but for a while after an altitude has been reached; and then later, even though the altitude is maintained, decreases slightly. Later the influence of diet upon metabolism at high altitudes will be added to this study. The effects of physical work will also be considered. For this purpose a bicycle ergometer will be used so that the amount of work can be exactly determined.

In connection with the above research the following experimental runs were made:

In the study of anoxemia as follows:	
By inhalation of nitrogen	15
Recoil board in low-pressure chamber (of these the records of 25 were destroyed in the fire)	36
Recoil board with rebreather	21
Capillary pressure determinations on rebreather	10
Effects of carbon dioxide with determinations on pulse rate, respiration, arterial pressure, capillary pressure, venous pressure, hand volume, blood flow, alveolar air, recoil board, and psychological effects	52
Effects of forced breathing of atmospheric air with determinations of hand volume, venous pressure, and capillary pressure	4
Determinations of the time of return to normal of arterial pressure and pulse rate after one hour's exercise	8
Experiments on Schneider index to determine effects upon it, of meals, coffee, chocolate, tobacco, day-to-day variations, and variations in time of day	396
24-hour cycles of Schneider index	14
Dermographia—Routine	66
Dermographia—Experimental cases	21
Effects of passive changes of posture with orientator	14

2. Aviation Medicine.

At the same laboratory the work of the problem of the effect of low oxygen on the heart by the electrocardiogram was continued up until the time of the fire. These records and most of those obtained during the previous year were damaged or destroyed in the fire. The electrocardiograph was damaged in the fire, and it has not been possible to operate it until recently. It is hoped that this work can be completed early this coming year.

The paper entitled "A Sphygmographic Study of the Pulse During the Rebreathing Test," by Dr. C. W. Greene and Dr. N. C. Gilbert, which was outlined in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920, was published in the Archives of Internal Medicine, volume 27, June, 1921. It was republished in the Air Service Information Circular, July 15, 1921, pages 115 to 120. "Studies on the Responses of the Circulation to Low Oxygen Tension" by the same authors, also outlined in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920, were likewise published in the Archives of Internal Medicine, the American Journal of Physiology, and in the Air Service Information Circular of July 15, 1921, as follows:

"Changes in the Pacemaker and in Conduction During Extreme Oxygen Want as Shown in the Human Electrocardiogram." Archives of Internal Medicine, volume 27, April, 1921, and Air Service Information Circular of July 15, 1921, pages 75 to 106.

"Stages in the Loss of Function of the Rhythm Producing and the Conducting Tissue of the Human Heart During Anoxemia." American Journal of Physiology, volume LVI, page 468.

The department of ophthalmology and otology and the department of psychology of the laboratory have collaborated in the problem on the determination of the effect of practise on nystagmus time. Preliminary work was completed for this experiment and apparatus being assembled, but it was destroyed by the fire and the work had to be done over again. The preliminary stage is again partly completed.

3. Neuro-Psychiatry.

The work in this department of the laboratory has been along the following lines:

1. Neuro-psychiatric examinations and personality studies.
2. A digest of the literature on neuro-psychiatry and a preparation of a series of papers on neuro-psychiatry to serve as a textbook in the School for Flight Surgeons.
3. A digest of the literature and analysis of the records and work of the laboratory on the subject of personality study. A paper has been prepared on this subject by Major Longacre and will be published shortly.
4. Clinical work.

In the routine work, special consideration was given personality study, in accordance with the revision made of proceedings and development along more comprehensive lines.

The series of papers alluded to above covers the entire study from descriptive psychology to and including personality study. The subject matter has been assembled from numerous sources and is presented in the form believed best suited to the needs of the flight surgeon and student within the limited time at his disposal.

The paper on personality study treats of—

(*a*) The meaning of personality.
(*b*) The purpose of personality study from the flight surgeon's viewpoint.
(*c*) Procedure in making personality study.
(*d*) Classification.

Each of these topics is elaborated in minutest detail with a wealth of material covering the subject from every point of view.

4. Ophthalmology and Otology.

At the laboratory further work on the perfection of ear plugs has been done and several hundred plugs have been sent out to the various flying fields. A report of this work, together with a description of the method of making the plugs, has been prepared by Major Tefft and Miss Stark, and will be published shortly. There are two types of plugs, one for summer use and the other for winter use, the difference being in the consistency of the plugs. They are manufactured from a mixture of beeswax and parresine on a core of lamb's wool. The plugs seem to keep out satisfactorily all the noise from the roar of the motor without interfering with the ability of the pilot to detect a skipping in his engine. They eliminate the temporary deafness which always results after prolonged rides in any plane or short rides in bimotored planes.

A study of the "speed of accommodation" in relation to the various phases of the eye examination given to fliers has been completed on 60 subjects, and a paper entitled "The Speed of Accommodation as a Practicable Test for Fliers," by Major Tefft and Miss Stark is now ready for publication.

The apparatus used in determining the speed of accommodation is the tachistoscope developed in 1918 by Prof. C. E. Ferree, of Bryn Mawr College. It is devised so that three test letters (two near, one at the left, the other at the right, and one far in the middle) are exposed simultaneously to the observer and are then cut off from his view one at a time in a fixed order. This is done by means of three sets of aluminum disks "of variable open and closed sectors turned by means of a bar fastened at its center to the axle to which the disks are attached and provided with adjustable weights on both arms." The two sets of disks which expose and exclude the near test letters are attached to the axle at the same point, but the one for the left letter is of shorter radius. The third set of disks controlling the exposure of the far test object is fastened to the axle behind the near test cards. "The length of exposure can be varied either by changing the width of the open sector or the position of the weights on the arm" of the bar.

The system of disks with the propelling bar operates behind a cardboard screen fastened to the framework of the apparatus. At the level of the test objects a narrow slit is cut in the screen through which the observer views the test letters.

The test letters are the illiterate E's mounted so that they can be rotated to point in the different directions, up, down, right, and left. The height of the near E is 0.8 mm., that of the far one 11.7 mm. Illumination for the near test cards is provided by a tubular tungsten lamp fastened to the top of the frame of the apparatus. This throws the light on the back of the cardboard screen and from there it is reflected to the test cards. Direct illumination on the far test card comes from a tungsten lamp mounted in a reflector.

In giving the test the subject is seated 30 cm. from the near test objects and 6 meters from the far one, with his head held in position by a Troland headrest. After a completed exposure he is required to report the direction in which each of the E's points. In order to perceive these successfully, he must first focus on the near E at his left, then adjust for the far E in the center, and finally accommodate for the near E at his right. After a short practice period the exposure times for each letter are gradually shortened until the subject's maximum speed is obtained. The various exposures, near, near to far, near to far and back to near, are recorded in terms of degrees of open sector and later converted into time by a process of calibration.

In view of the following facts it is not recommended that the test for speed of accommodation be incorporated at this time in the 609 examination. The apparatus in its present form is cumbersome and its operation requires too specialized a technique for use in a routine examination. Many subjects find difficulty in adjusting to this particular test situation. The memory factor seems to be almost as important as proper eye functioning. The test as given undoubtedly places much greater strain on the eyes than is required in any flying situation. Finally with the exception of presbyopic cases those who possess a slow speed of accommodation seem to possess other visual deficiencies which can be more easily detected.

Two papers on the Retinal Sensitivity Apparatus, discussed in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920, have been written

by Dr. P. W. Cobb and M. W. Loring, formerly of the staff, on their work with this apparatus while at the laboratory. One is entitled "A Method for Measuring Retinal Sensitivity." It was published in the Journal of Experimental Psychology, June, 1921. The other paper will be published shortly and is entitled "Individual Variations in Retinal Sensitivity and Their Correlation with Ophthalmologic Findings."

The study of depth perception referred to in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920 is considered under Aviation Psychology.

The research work planned for the past year on nystagmus time was interfered with by the fire, and reference to the progress of this work has already been considered under Aviation Medicine.

The work planned to determine the factor of the association of reaction time with depth perception and the effect of altitude on hearing and vision has been impossible because of the destruction of apparatus and equipment caused by the fire. This work is now ready to go ahead again.

5. Aviation Psychology.

Several complete standard psychological set-ups have been assembled—one for use at the laboratory to replace one destroyed by fire, the others to provide practice for the student officers or to be sent to branch units as required.

The statistical study of types of motor responses shown during the first three minutes of the rebreathing test was extended to include 600 records from other flying fields, in addition to the 600 records originally used. Comparisons between the groups selected according to the type of response were made with respect to the character, quality, and length of run, and the final oxygen, rating, and score. The completion of this work was hindered by the fact that a large part of it was destroyed by fire and water, and the material had to be reassembled, recalculated, and the curves redrawn. The study is now complete.

The majority of reactors present a type of motor response which is steady, slow, and accurate, in contrast to the other large group of reactors whose responses are impulsive, hesitant, and inaccurate. Comparisons of these two classes show the former to be superior in every way. The initial failure of attention and the ability to coordinate properly and the complete failure of these faculties occur later and at lower oxygen per cent than is the case in the second group; the run is of longer duration and the final oxygen per cent is lower. Of the first group, 60 per cent are rated "A," 31 per cent "B," and 8 per cent "C" as compared with the second group, of which 30 per cent are rated "A," 48 per cent "B," and 22 per cent "C." In as far as ability to preserve his attention and voluntary control at altitudes, as shown by the rebreathing test, is concerned, these results indicate that the reactor whose responses are steady and accurate is superior to the one who shows impulsive, hesitant, and inaccurate tendencies.

A paper on the "Psychological Effects of Aviation on the World," was prepared at the request of the Military Intelligence Department, by Miss Deyo.

By the departments of aviation psychology and aviation physiology of the laboratory, a statistical study of the relationship between pulse increase, respiration response, final oxygen, and the oxygen percentage at which complete failure of motor coordination and attention occurred, as shown on the rebreather, was completed. From the same records another study was made of the final oxygen to (1) systolic increase, (2) diastolic increase, (3) pulse pressure increase, and (4) respiration response. The results of these two studies have not yet been written.

Suitable psychological tests for use in the low-pressure chamber have been devised. It is planned to have these experiments test the degree and fluctuation of attention, degree of motor incoordination, powers of association and retention at varying oxygen levels, and the power properly to perceive and retain impressions at a high altitude. These tests have been tried out under normal conditions upon a number of subjects preliminary to their use in the low-pressure chamber.

A paper called "Monocular and Binocular Judgment of Distance," based upon data collected by Capt. B. H. Palmer, formerly of the ophthalmology department, was written by Miss Deyo and will be published shortly. The subjects, who were Army officers and men, were given the routine eye examination for fliers, which included the visual acuity for each eye, the angle of convergence, judgment of depth perception using binocular vision, and, in addition, judgments of depth perception using monocular vision. There are such great differences in judgments of depth perception made with monocular vision and with binocular vision (the former being uniformly poorer) that it is evident that good binocular vision is necessary for accurate judgment of distance, and the results show that the better the visual acuity the more accurate the depth perception judgments tend to be.

Two papers reviewed in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920 have been republished in the Air Medical Service Information Circular of July 15, 1921. They are:

"Psychological Research in Aviation in Italy, France, England, and the A. E. F.," by F. C. Dockeray and S. Isaacs, formerly of the laboratory staff, pages 26 to 37.

"Psychological Effects of Deprivation of Oxygen. Deterioration of Performance as Indicated by a New Substitution Test," by H. M. Johnson and F. C. Paschal, formerly of the laboratory staff, pages 38 to 72.

6. Miscellaneous.

A paper was published this year in the Air Service Information Circular for July 15, 1921, on pages 134–139, entitled "A Brief Note on the German Liquid Oyxgen Apparatus." This was compiled by Dr. George B. Obear while attached to the laboratory staff, and published following his discharge from the service. The paper gives a detailed description of three types of the apparatus received at the laboratory and summarizes the advantages and disadvantages of a liquid-oxygen apparatus.

The plans for the Eagle airplane ambulance, mentioned in the report of the Medical Research Laboratory and School for Flight Surgeons for 1921, were carried out and the alterations made. The ship carried four patients in litters and two sitting. There was also room for a surgeon next to the pilot, and a first-aid cabinet was installed near the front of the cabin. Unfortunately before the ship was thoroughly tested out as an ambulance it was wrecked.

There are two fields of usefulness for airplane ambulances. One is in attending crashes. For this purpose the machine must be small and easily handled. It will be able to carry only one, or at the most two patients. Crashes are

apt to happen in places where an airplane can not make a satisfactory landing. The other field is in transporting patients from one hospital to another or from the front to the rear in war time. It is believed this will prove to be the field of greatest usefulness. Large planes can carry several patients and carry them in comfort with less danger and with greater rapidity than any motor ground ambulance can ever hope to do.

II. SCHOOLS OF INSTRUCTION.

1. Instruction for Flight Surgeons.

The only school of instruction is the School for Flight Surgeons located at the Medical Research Laboratory, Mitchel Field. This school is unique and a description of its organization and work would seem worth while. The school is located at and operated by the personnel of the laboratory. It has a commandant, who has charge of the instruction and administration; assistant commandant and director of the department of neuro-psychiatry, who conducts the details of administration of the school and acts as librarian; executive and supply officer, who also acts as secretary of the school and is custodian of its records. The faculty board consists of the commandant, ex-officio, assistant commandant, secretary, and directors of the departments. The school is divided into the departments of aviation medicine, aviation psychology, ophthalmology, and otology, aviation phychology, neuro-psychiatry, supply and engineering, and administration and equipment. The board has charge of all matters relative to the standing, rating, and efficiency of all students, and also acts on such other matters as may be referred to it by the commandant. The directors of the departments and certain assistants are instructors.

The course covers three full months, and classes are held from 9 a. m. to 4.30 p. m., except Saturday, when the hours are from 9 a. m. to 12 m. The course consists of lectures, clinics, quizzes, practical work, demonstrations, prescribed and collateral reading. At the end of the course a general qualifying oral examination is given by the faculty board. Each student must be qualified to perform the flying examinations, both 609 and rebreather, and must obtain an average of 80 per cent in all subjects and not fall below 75 per cent in any of the five major subjects. The student who attains an average of 90 per cent or over is graduated with honor. In addition, each student is rated on his aptitude for flight surgeon's work, regardless of his professional ability. Rating are made on the scale of "A" above average, "B" average, and "C" below average.

The faculty board consists of the following:

Maj. L. H. Bauer, commandant and director of the department of administration and equipment for flight surgeons.

Maj. Lloyd E. Tefft, director of department of ophthalmology and otology.

Maj. R. F. Longacre, assistant commandant and director of department of neuro-psychiatry.

Capt. J. B. Powers, director of department of aviation medicine.

Dr. E. C. Schneider, director of department of aviation physiology.

Miss Barbara V. Deyo, director of department of aviation psychology.

Miss Dorothy Truesdell, acting director of department of aviation physiology.

The following have acted as instructors in addition to the members of the faculty board:

Capt. Ira F. Peak, instructor in neuro-psychiatry.

Miss Elizabeth K. Stark, instructor in ophthalmology and physiological optics.

The synopsis of the course follows:

DEPARTMENT OF AVIATION PHYSIOLOGY.

The lecture covers the following:

- Introductory and general.
- Physiological aspects of aviation.
- Physiological effects of climatic factors other than altitude.
- The hematorespiratory function of the blood.
- Laws of respiratory absorption and dissociation.
- The demand for oxygen and rate of oxygen consumption.
- Anoxemia; classification and methods of producing each kind.
- Altitude sickness and the symptoms of other low oxygen experiences.
- The compensations to low oxygen, with comparisons of the temporary and permanent varieties of reaction in the following:
  - Respiration.
  - Blood.
  - Hematorespiratory function of the blood.
  - Circulation.
  - Metabolism.
- Physiology of muscular exercise, including muscles, body temperature, respiratory, circulatory, and metabolic changes.
- Physical fitness. Comparison of trained and untrained.
- Fatigue and staleness.
- The measurement of fatigue and fitness.
- Types of response in rebreathing.
- Color reactions on the rebreather.
- The practical work includes brief lectures, demonstrations, as well as practical work on the following:
- The Henderson rebreather and the Larsen rebreather—
  - The work includes the set-up, calibration, preparation, and operation in practice and official runs of both machines, including the work of the physiologist, machine men, and the blood-pressure man.
- Gas analysis and the preparation of solution and set-up of apparatus.
- The Schneider index.
- Plotting and preparation of rebreathing records.
- Rating.
- The low-pressure chamber—
  - (a) Pulse and blood pressure.
  - (b) Alveolar air.
- Consideration of the English tests for fliers, and also Dreyer test, Martin test, and other tests.

DEPARTMENT OF AVIATION MEDICINE.

The lectures and practical work cover the following:

1. Cardiac pathology.
2. Sounds and murmurs, normal and abnormal.
3. Valvular defects.
4. Affections of heart muscle associated with retrograde changes, infiltration, and subsequent repair.
5. Affections of the heart due to exogenous and endogenous influence.
6. Myocarditis in acute infection.
7. Anaphylactic heart.
8. The arrhythmias.
9. Neuro-circulatory asthenia.
10. General physical examination and physical examination for flying.
11. The rebreather and low pressure chamber from a clinical standpoint.
12. X ray and fluoroscopy.
13. The electrocardiograph and the polygraph.
14. The heart in aviation.
15. Series of clinics at Bellevue Hospital, New York City.
16. Frequent demonstrations and quizzes.

DEPARTMENT OF AVIATION PSYCHOLOGY.

The lectures cover the following:

1. The standard psychological test.
2. General psychological principles.
3. Psychological tests for efficiency.
4. Apparatus and wiring.
5. Emotion and its relation to efficient reaction.
6. Psycho-physical tests—
   (*a*) American.
   (*b*) Foreign.
7. Effects of alcohol and caffeine on efficiency.
8. Tests used by psychologists in A. E. F.
9. Rating.

There is in addition practical work with the rebreather and the student acts as psychologist on as many official runs as possible, also practical work on apparatus and wiring, and on psycho-physical tests.

DEPARTMENT OF NEURO-PSYCHIATRY.

Psychiatry.—Lectures and quizzes on the following:

1. Descriptive and genetic psychology.
2. The nature, causes, general symptomatology, and classification of mental disorders.
3. Dementia precox.
4. Manic depressive psychosis.
5. Paresis.
6. The paranoias.
7. Psychoses associated with organic diseases and injury of the brain.
8. Symptomatic, infection-exhaustion, and toxic psychoses.
9. Presenile, senile and arteriosclerotic psychoses.
10. Borderland and episodic states comprising constitutional psychopathic inferiority and the psychoneuroses.
11. Defective mental development.
12. Methods of examination.
13. The neurological examination for flying.
14. Personality study.
15. Practical work and a series of clinics at Bellevue Hospital and Brooklyn State Hospital.

Neurology.—The studies in neurology comprise cerebral and segmental localization, conduction pathways, and nerve distribution as developed by the intensive studies made of pupillary reactions, station, gait, reflexes, tic, and tremor; the significance of the normal and abnormal findings in the complete neurological examination.

Because of the intensive nature of the course, it has been found necessary to present the subject matter along lines differing somewhat from those followed in the usual textbooks. Fundamentals are presented clearly and concisely with the fullest development of the subject possible in the time allotted. The papers already referred to under "Research" serve as the textbook.

DEPARTMENT OF OPHTHALMOLOGY AND OTOLOGY.

Ophthalmology.—Lectures, quizzes, demonstration, and practical work. This includes practice in the ophthalmological section of the 609 Examination, including set-up and use of apparatus, ophthalmoscopy, and retinoscopy.

The importance of the eye in flying is emphasized.

The following subjects with their special adaptations to flying are covered in the lectures and quizzes.

Anatomy of the eye.
External, subjective and objective examination of the eye.

Brief consideration of diseases of:

The lids.
Lachrymal apparatus.
Orbit.
Conjunctiva.
Cornea.
Sclera.
Iris.
Ciliary body and choroid.
Vitreous.
Lens.
Retina.
Optic nerve.
Glaucoma.
Disturbance of vision.
General optical principles.
Refraction.
Retinoscopy.
Accommodation.
Convergence.
Extrinsic muscles.
Disturbances of motility.
Ocular manifestations of general diseases.

Otology.—The lectures and practical work cover the following:

Anatomy and histology of ear, nose, and throat.
Pathology and treatment of ear, nose, and throat, conditions commonly met.
The inner ear—
Reaction, nystagmus, past pointing, falling.
Brain tracts.
Associated centers, etc.
The 609 examination.
Orientator.

DEPARTMENT OF ADMINISTRATION AND EQUIPMENT FOR FLIGHT SURGEONS.

Lectures and demonstrations on the following:

1. The various gas and liquid oxygen supply apparatuses.
2. Methods of testing the instruments.
3. Proper installation.
4. Advantages and disadvantages of the various instruments.
5. Comparison of the foreign and American flying examinations.
6. Aviation accidents.
7. Duties of the flight surgeon.
8. Paper work and practical work on the flying field.
9. Work and records of branch and field units.
10. The equipment for flight surgeons, rebreather and field units.

There is prescribed and collateral reading in connection with each subject.

I desire to acknowlege the courtesy rendered by, and the obligations of the school to the members of the staffs of the Bellevue Hospital, New York City, and the Brooklyn State Hospital.

2. INSTRUCTION FOR ENLISTED MEN.

This school has been nonoperative during the past calendar year, as no students were detailed for instruction. It is believed this phase of work should be further developed, for flight surgeon's assistants and assistants for rebreathing units can be more satisfactorily trained at the laboratory than by the individual flight surgeon. These men should be trained as follows:

A. *Department of aviation physiology.*—Practical work on the Henderson and Larsen rebreathers, including set-up, calibration, preparation, and operation of both machines; the taking of blood pressure and pulse; gas analysis and the preparation of solutions, and set-up of apparatus; plotting and the preparation of rebreather records; the Schneider index.

B. *Department of ophthalmology and otology.*—The set-up of apparatus and the operation of the Barany chair; the recording of the results of the examination.

C. *Department of administration and equipment for flight surgeons.*—The paper work of a flight surgeon's office; the paper work of rebreathing units; care and set-up of equipment for flight surgeons, rebreathing units, and field units.

The course should cover a period of two months.

3. LIBRARY.

The library of the laboratory and school, which is under the immediate charge of the assistant commandant and the library committee, had to start all over again, following the fire.

A good working library is essential both for research and for the school. Effort is being made to procure all articles concerning aviation medicine, and also books and periodicals relating to the specialties allied to aviation medicine. Special attention is paid to physiology, physiological chemistry, neurology, psychiatry, psychology, ophthalmology, otology, roentgenology, and cardiology.

There are at present 740 volumes and pamphlets in the library.

III. ROUTINE WORK.

It seems worth while to outline the routine work which is done in aviation medicine. A great part of this is done at the Medical Research Laboratory. However, flying examinations are done at all Air Service stations by various flight surgeons, and their work is exceedingly important and much valuable information is derived from their findings on these examinations and in their care of the fliers.

1. PHYSICAL EXAMINATIONS.

All the physical examinations for flying, according to Form 609 W. D., A. G. O., for the personnel of Mitchel Field and for this section of the country, are made at the laboratory. Likewise all altitude classification tests are made there. Various special examinations are made, and border-line cases have been referred there for examination and recommendation.

All the physical examinations for flying are made by the specialists in the various departments. A board of officers from the departments of aviation medicine, neuropsychiatry, and ophthalmology and otology considers the case of every applicant who is rejected on any point in the 609 examination. A recommendation is made to the Chief Surgeon, Air Service, for or against a waiver in that particular case. In addition to the requirements of the 609 examination, each subject is given a Schneider index, his heart is fluoroscoped, an X-ray picture is taken of the chest, and also one is taken of the head to determine the condition of the sinuses. These X-rays are filed with his record for future reference. A personality study is likewise made of every candidate. The classification tests are conducted in conjunction by the departments of aviation medicine, aviation physiology, and aviation psychology.

2. BRANCH LABORATORIES.

There are branch rebreathing units maintained at Kelly, March, and Carlstrom Fields, and at the Army Medical School, where altitude classification tests are made. These units are supplied by the laboratory. All their records are first forwarded to the laboratory for examination and revision to insure accuracy and uniformity in the tests and ratings. These records are carefully examined and checked in the departments of aviation medicine, aviation physiology, and aviation psychology.

3. X-RAY AND PHOTOGRAPHY.

The department of aviation medicine of the laboratory has a subsection devoted to X-ray and photography. This section carries on research in connection with the department of aviation medicine and other departments. The electrocardiograph is used for both research and instruction and in examinations. Photographic work consists of:

Still photography of apparatus and equipment.
Charts both for publication and instruction purposes.
Motion picture photography for the same purposes.

A summary of the X-ray work is as follows:

X-ray pictures, 410.
Fluoroscopy on all 609 examinations.

A summary of photography is as follows:

Charts photographed for reproduction, 92.
Still photography of apparatus and equipment, 29.
Prints of charts and stills, 318.
Motion pictures, approximately 5,300 feet.

In connection with motion pictures a complete record was made of the 609 examination from start to finish, all of which was destroyed in the fire, and which will have to be made over again.

A summary of the routine work of the laboratory follows:

- Flying examinations according to Form 609 W. D., A. G. O., 199.
- Altitude classification tests, 55.
- Altitude classification tests from branch units revised at the laboratory, 162.
- Personality studies, 207.
- Special examinations, approximately 60.
- Electrocardiograms, 475.
- X-ray and photographic work as outlined above.

These are all in addition to the experimental examinations mentioned under the head of "Research."

The Air Service Information Circular of July 15, 1921, was proof read at the laboratory.

Work has been started on drawing up a set of training regulations for airplane ambulances.

4. Personnel.

It will probably be interesting to know how great a personnel has been necessary to carry on the work outlined above at the laboratory and school.

(a) officer personnel.

The number of the permanent officer personnel throughout the year was 8. Of these 1 was on sick report the entire year. Of the other 7, 1 was commandant, 1 executive and supply officer (an administrative corps officer), 3 are directors of departments, and 2 assistants in departments.

All of the medical officers are qualified flight surgeons. It is important that the officers selected for duty in the organization are well qualified for work in the particular departments to which they are to be assigned. Every officer here should be qualified in one of the particular specialties that are important to aviation medicine.

(b) civilian personnel.

There are 18 civilian employees at present in the laboratory; 7 are scientific, 6 technical, 3 clerks, and 2 janitors. Two of the departments have only civilians among the personnel. These are the departments of aviation physiology and aviation psychology. The work of these departments is so special and technical that no officers or enlisted men are qualified for it. The scientific personnel have been at the laboratory from a year and a half to two and a half years. They are well trained and thoroughly familiar with their work. Their qualifications are special and they could not be replaced.

IV. THE FUTURE OF AVIATION MEDICINE.

Future work in this subject seems endless. There are fields which have been touched only lightly or not at all. For example, the effect of wind, one of the most trying things the aviator has to combat, is a subject about which very little is known. It is contemplated in the future to build a wind tunnel in the Research Laboratory and to do experimental work along this line. The subject of aviator's clothing is another which is not thoroughly satisfactory. There are still factors in connection with altitude that are not satisfactorily settled. The question of reaction time, particularly in estimating distance and in certain other factors in the physical examination, is important, undoubtedly, and yet there is very little on which to base a statement about it. The effect of cold is another subject on which work has not yet been started. The Medical Research Laboratory has a refrigerating apparatus in connection with its low-pressure chamber with which it is intended to experiment in order to determine satisfactorily the effect of not only cold but cold combined with altitude. The subject of fatigue has yet many sides to be investigated.

The National Research Council has appointed a large committee to consider the feasibility of an extended investigation of the relation of air to health. After a comprehensive plan of study had been formulated, a subcommittee consisting of Prof. W. H. Howell, of Johns Hopkins University, Dr. Yandell Henderson, of Yale University, and Dr. E. C. Schneider, of Wesleyan University and director of the department of aviation physiology at the Medical Research Laboratory, was appointed to take charge of the research experiments. The subcommittee has proposed as the first problem for investigation, "The physical effects of various combinations of temperature, moisture, and air movement." Since the effects of temperature and wind are pertinent to the health of the aviator, and are problems which the laboratory has had in view for some time, it is believed that the department of physiology of the laboratory should cooperate with the committees of the National Research Council and carry out there some of the phases of this program of investigation. The low-pressure chamber with its refrigerating equipment meets an important requirement for experimental observation. One of the prime objects of the National Research Council is to coordinate research throughout the country. It is believed that this organization has an opportunity now, not only to produce work which will be of benefit to aviation, but of value to the whole world.

The School for Flight Surgeons needs but little comment. It is believed it has now reached a point where its value is recognized and where it is on a solid foundation. Little change is contemplated in the course in the near future, except such additional information as may be acquired through research. It is believed the question will soon arise, however, as to whether or not the course should be extended beyond the allotted period of three months. The amount of work crowded into the three months is very great. The student's entire time is so occupied that he has difficulty in keeping up with the pace set.

It is believed that one way in which the laboratory could be of greater value to the service has not been properly developed, and that is its relation to the flight surgeon in general. Effort has been made to keep in touch with the flight surgeon after he graduates from the school, and this effort has met with some success in some instances. It is believed, however, that if some arrangement could be made whereby flight surgeons in the field were called upon to report periodically on certain phases of their work to the laboratory, that much valuable information might be acquired. In the reports of the Medical Research Laboratory and School for Flight Surgeons for 1919 and 1920, recommendation was made that once a year some officer from the laboratory be detailed to visit the branch rebreathing units to inspect the work being done there and

coordinate it with that of the main laboratory. In addition, he could check the work of the flight surgeon. It is believed that the work of the branch units and that of the flight surgeons could be made more efficient by their being kept in closer touch with the laboratory. Coordination brings about that standardization of work which is both desirable and essential in the Air Medical Service.

The order issued about a year ago removing flight surgeons from flying status has, as prophesied, worked serious harm. Medical officers are less anxious for the work when they can not be placed on flying status, and their value and enthusiasm are decreased. There are certain phases of flight surgeons' work that can be accomplished only by a personal knowledge of flying. It is not necessary that all flight surgeons become pilots, but it is absolutely necessary that they have some practical experience in the air. It is not possible for them to have as good an interpretation of the problems of flying from the medical side of aviation without this practical experience. It is certainly most unjust to expect these officers to fly regularly and frequently as they should do, unless they can receive the same compensation that other officers receive.

I desire to express my thanks to Dr. Edward C. Schneider, Miss Dorothy Truesdell, Miss Barbara V. Deyo, and Miss Elizabeth K. Stark for assistance in compiling this article.

THE SPEED OF ACCOMMODATION AS A PRACTICABLE TEST FOR FLIERS.

By Maj. Lloyd E. Tefft, *Medical Corps*, and Elizabeth K. Stark, *Department of Ophthalmology, Medical Research Laboratory and School for Flight Surgeons, Mitchel Field, Long Island, N. Y.*

PURPOSE.

It was believed that the speed of accommodation of the eyes possessed by a pilot played an important part in flying, especially in combat work, landings, and other manoeuvers in which it was necessary for a pilot to focus his vision from far to near objects and vice versa.

Research work was accordingly undertaken in this laboratory to ascertain the relationship, if any, of the speed of accommodation to other properties of the eyes, such as visual acuity as manifested by the ability to read Snellen test type at 20 feet; depth perception as elucidated by the Howard-Dolman depth perception apparatus; the power of accommodation as determined with the Prince rule; the strength of the internal and external recti muscles as measured by the angle of convergence and the power of prism divergence; retinal sensitivity as obtained from the Cobb retinal sensitivity apparatus. For this purpose 60 subjects were examined and the results charted and correlated with the various parts of the eye examination given to fliers as well as with the retinal sensitivity test.

The subjects, according to the results of the eye examination were divided into three classes: (1) A general classs embracing both those qualified, and those disqualified because of ocular defects other than speed of accommodation, (2) those qualified and (3) those disqualified by the examination. Means were established on each of these classes to determine if any candidates, otherwise qualified for flying, would be disqualified because of possessing a low speed of accommodation, and to establish, if possible, a lower speed limit for all cases presenting themselves for examination. Also it was desired to ascertain if there were any candidate otherwise disqualified possessing a high speed of accommodation.

TECHNIQUE.

The apparatus used in determining the speed of accommodation was the tachistoscope developed by Prof. C. E. Ferree, of Bryn Mawr College.[1]

It is devised so that three test letters (two near, one at the left, the other at the right, and one far, in the middle) are exposed simultaneously to the observer and are then cut off from his view one at a time in a fixed order. "This is done by means of light-weight disks of variable open and closed sectors turned by means of a bar fastened at its center to the axle to which the disks are attached and provided with adjustable weights on both arms." "The length of exposure can be varied either by changing the width of the open sector or the position of the weights on the arms."

The test letters used were the illiterate E's, mounted so that they could be rotated to point in different directions. The working distance of the far test object was 6 meters and of the near test objects 30 centimeters; the visual angles subtended in each case were 6 minutes 42 seconds and 9 minutes 10 seconds. The brightness of the far test card was 10.40 candles per square foot; of the right and left test cards 1.68 and 1.16 candles per square foot, respectively.

After a completed exposure the subject was required to report the direction in which each of the E's was pointed. In order to perceive these successfully, he had first to focus on the near E at the left, then adjust for the far E in the center, and finally accommodate for the near E at the right. After a short practice period with slow speed, the exposure times for each letter were gradually shortened until the point was reached where the subject could just discriminate each. Then three correct judgments out of a possible five for a given setting of disks were required. The various exposures; near, near to far, near to far and back to near were recorded in terms of degrees of open sector and converted into time by a process of calibration. In working up the results, however, only the total time required for the complete excursion was used.

RESULTS.

The two curves show the distribution of results for the 60 cases examined in our series and for the 100 cases examined by Goodall.

Table I gives the means and medians together with the probable errors of the results obtained. The means and medians of Goodall's cases, 89 of whom were aviators, have been computed and added for their comparative value.

Table Ia shows these same central tendencies when extreme cases have been omitted by Chauvenet's criterion.

Table II gives correlation values between speed of accommodation and the results of the various phases of the eye examination for fliers as well as with a retinal sensitivity test and with age.

Table III gives the speed of accommodation and the refractive correction of those cases disqualified because of high refractive error.

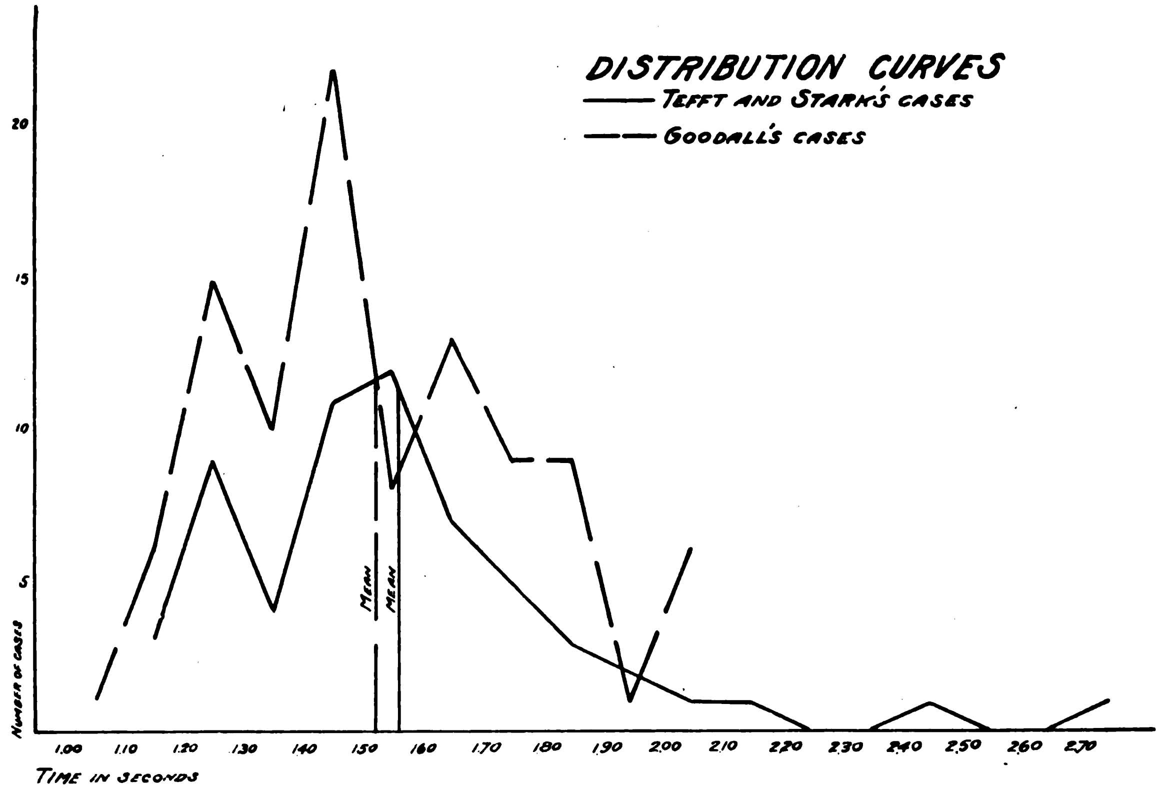
[1] For a detailed description of the apparatus, see C. E. Ferree and Gertrude Rand, The Inertia of Adjustment of the Eye for Clear Seeing at Different Distances, American Ophthalmological Society's Transactions, 1918. Edwin B. Goodall, The Speed of Accommodation, Air Medical Service Circular, March, 1920.

DISCUSSION AND INTERPRETATION OF RESULTS.

As appears in Tables I and Ia and the distribution curves, our results were essentially the same as those obtained from Goodall's data. The eliminating of extreme cases from our group renders our mean almost identical with that obtained from his results. Although the mean time for the 16 cases which were disqualified by the eye examination given to fliers is somewhat higher than that for the 44 cases which were qualified, this difference as measured by its probable error is not great enough to be significant.

TABLE II.

Type of test.	Number of cases.	r	P.E.,r
Visual acuity R. E.	60	0.307	±0.079
Visual acuity L. E.	60	0.326	±0.078
Depth perception	60	0.336	±0.077
Prism divergence	60	0.009	±0.087
Av. accommodation for 2 eyes	60	0.369	±0.075
Angle of convergence	60	0.240	±0.082
Retinal sensitivity	60	0.167	±0.084
Age	60	−0.331	±0.078
Age, cases qualified by eye exam	44	−0.526	±0.075



Two cases whose speed was so slow as to permit their elimination on the basis of Chauvenet's criterion were qualified by the examination. This was undoubtedly a matter of age, as the high negative correlation between speed and age (Table II) becomes practically negligible when these cases are eliminated (Table IIa). The two men were 37 and 39 years of age, and their slow speed is interpreted as being indicative of the initiation of presbyopia.

TABLE I.

	Number of cases.	Mean P. E. secs.	Median P. E. secs.
Entire group	60	1.563±0.026	1.525±0.032
Qualified by eye exam	44	1.536±0.031	1.500±0.039
Disqualified by eye exam	16	1.637±0.044	1.575±0.055
Goodall's group	100	1.526±0.017	1.482±0.017
Aviators Goodall's group	89	1.505±0.015	1.468±0.022

TABLE Ia.—*Extreme values omitted by Chauvenet's criterion.*

	Number of cases.	Mean P. E. secs.	Median P. E. secs.
Entire group	58	1.528±0.020	1.517±0.025
Qualified by eye exam	42	1.496±0.021	1.498±0.026

TABLE IIa.—*Extreme cases of Table II omitted by Chauvenet's criterion.*

Type of test.	Number of cases.	r	P.E.,r
Visual acuity, R. E.	57	0.235	±0.084
Visual acuity, L. E.	57	0.406	±0.075
Depth perception	57	0.244	±0.085
Prism divergence	57	−0.052	±0.089
Av. accommodation	58	0.204	±0.085
Angle of convergence	58	0.250	±0.083
Retinal sensitivity	57	0.210	±0.085
Age	58	−0.097	±0.088
Age, qualified by eye exam	42	−0.166	±0.111

TABLE III.

Subject.	Time secs.	Refraction. R. E.	Refraction. L. E.
G. B. M.	1.226	+2.25 Sp.	2.50 Sp.
J. J. M.	1.468	+1.25 Sp.+0.25 cyl. ax. 90°.	1.25 Sp.+0.75 cyl. ax. 90°.
J. H. H.	1.487	+3.00 Sp.	3.00 Sp.
H. T. D.	1.542	−0.75 Sp.+1.50 cyl. ax. 90°.	−0.75 Sp.+1.50 cyl. ax. 90°.
A. C. M.	1.698	+2.25 Sp.+0.50 cyl. ax. 90°.	2.25 Sp.+0.50 cyl. ax. 90°.
V. T. S.	1.995	−1.75 Sp.	−1.75 Sp.

It has been suggested that these two cases might have been disqualified if the disqualifying limit for the power of accommodation were made more rigid. At present, a leeway of two diopters above or below the normal for each age as determined by Duane, is allowed. The normal power of accommodation for the ages 37 and 39 according to Duane's table is 6.8 and 6.2 diopters, respectively. The actual power of accommodation of the two cases in question was for the one case, 6.5 D both eyes, and for the other, 5.25 D., R. E. and 5.00 D., L. E. Although both of these cases are below the normal, they are well within the two diopter limit set. Where the question of speed is not involved the eye can, no doubt, in certain cases, exercise a degree of accommodative effort sufficient to overcome a certain amount of its accommodative deficiency.

Visual acuity, depth perception, and extent of accommodation all show a moderate degree of correlation with speed, but with the omission of extreme cases the correlation between the visual acuity of the left eye and speed of accommodation becomes the most significant. The power of prism divergence bears no relation at all to speed of accommodation as judged from the value of r obtained; and the correlation between retinal sensitivity and speed is not high enough to be significant.

It will be seen from Table III that the six cases disqualified because of high refractive error have a wide range of speed, one of them falling in the group of the best 15 per cent of the cases and another among the poorest 15 per cent. These few cases show no correspondence between decreased speed and extent of refractive error.

If we were to adopt 2 seconds as the lower speed limit, 4 of our 60 cases would be disqualified because of slow speed of accommodation, the two qualified cases already discussed and two others which were disqualified by the eye examination. Both of these latter two had defective depth perception, and one had visual acuity of less than 20/20 as well. From Goodall's group this limit would disqualify 6 cases, 4 of whom were fliers.

If the limit were made 1.90 seconds, two more of our cases would be disqualified, making a total of 6. But these two cases were also disqualified by the eye examination, one because of defective visual acuity, depth perception, muscle balance, angle of convergence, and refraction; the other because of sub-normal visual acuity. Turning to Goodall's data, we find that this limit would eliminate 7 of his cases, 5 fliers, whose number of flying hours ranges from 90 to 250.

CONCLUSIONS.

1. While this method of testing speed of accommodation is satisfactory in determining the actual speed, unquestionably it is also a test, to a certain extent, of immediate memory. Many of the subjects complained that they could not remember the sequence in which the letters disappeared, although they felt confident that they had seen all the letters correctly.

2. The apparatus in its present form is cumbersome and the intricacies of operating it are too numerous to make it feasible for use in a routine examination. Another drawback to its use is found in the fact that a large number of subjects seem to find difficulty in adapting themselves to this particular test situation and require a long practice period before they can make a correct report of all three test letters. In certain cases, however, it might be used advantageously.

3. While most of the subjects of this series were nonfliers, the results obtained on them do not justify the conclusion that fliers (Goodall's group) possess a materially faster speed of accommodation than nonfliers.

4. While the theoretical importance of the speed of accommodation is recognized, it is believed that those possessing a degree of speed of accommodation which might endanger their flying, possess other deficiences which can be more easily detected. A possible exception might be found in cases where presbyopia has begun. Since the other tests disqualify the majority of cases with slow speed of accommodation, it is not necessary to establish a disqualifying limit for speed of accommodation. On the other hand, this test could not supplant the routine examination, as a number of disqualified candidates showed better than average speed of accommodation.

5. According to the observations of one or two fliers, this test as given, places much greater strain on the eyes than is required in any flying situation. This is undoubtedly true, since the figures on the dials of the plane are farther away and subtend a larger visual angle than the near E's used in the test. If this test were to be adopted as a routine test, it would be better to establish standards using larger test type, thereby more nearly duplicating flying conditions.

—By courtesy of the American Journal of Ophthalmology.

MONOCULAR AND BINOCULAR JUDGMENT OF DISTANCE.

By Barbara Valette Deyo, *Department of Aviation Psychology, Medical Research Laboratory and School for Flight Surgeons, Mitchel Field, Long Island, N. Y.*

The material for this article was obtained by Capt. Bascom H. Palmer, Medical Corps, ophthalmologist at the Medical Research Laboratory, Mitchel Field, N. Y., from the examination of 100 subjects comprising airplane pilots and officers and men of other branches of the service. His problem was to investigate the quality of depth perception judgment, as measured by the depth perception apparatus, and compare the judgments made with monocular and binocular vision. The following data were complete for each subject: (1) Ten judgments of depth perception (measured in millimeters) using binocular vision; (2) 10 judgments using the right eye only; (3) 10 judgments using the left eye only; (4) the visual acuity for each eye, tested by the Snellen test types; and (5) the angle of convergence. In each case it was noted whether the sighting eye was right or left.

The subjects were given the standard examination for flying and were rated qualified or disqualified on the findings of the examiner.

For measuring visual acuity the regulation Snellen test charts were used, the examinee occupying a chair 20 feet away from the wall upon which the charts were arranged. To qualify on this test the subject must have a visual acuity of 20/20 for each eye. The instrument with which the judgments of depth perception are made is known as the depth perception apparatus. It may be described as the front, back, and floor of a rectangular box, the sides and top of which are open. The floor is 21¾ inches from front to back and 13¼ inches wide, and the height of the back and front is 11½ inches. In the front is cut a window whose lower margin is 4 inches from the floor and whose outer margin is 2¾ inches from the side of the apparatus. The entire apparatus is painted a dull black and the anterior surface of the back covered with a square of dead-white cardboard.

From front to back of the floor of the apparatus runs a scale ruled off into centimeters and divided into millimeters. Beginning at the front end of the box the scale is numbered from 500 mm. up to 1,450 mm. A dead-black rod 6 inches high and three-eighths inch in diameter is placed in a stationary position at the point on the scale marked 1,000, and a second rod, identical in size with the first, sliding in a groove which runs the length of the box, may be set at any point on the scale by means of adjustable pulleys. The apparatus is placed directly before and beneath the Snellen charts and illumination is provided for both by one 200-watt daylight Mazda lamp, with an angle reflector installed about 4 feet above and in front of the test charts.

The applicant is seated 6 meters from the stationary rod in the apparatus. He is first given the opportunity of seeing the rods in the same plane, then by means of lines attached to the pulleys attempts to bring the adjustable rod in the same plane with the stationary rod after the rods have been widely separated by the examiner. The test is repeated 10 times, the subject's estimations of depth difference being read in millimeters directly from the scale.

Care is taken by the examiner to avoid casting a shadow on the background and to avoid giving the subject any indication as to whether he is doing poorly or well. In order to prevent motion parallax the applicant should also be instructed to hold his head straight. An average depth perception of more than 30 mm. disqualifies the subject.

Depth perception or judgment of distance is important in aviation in the making of landings, where the pilot must accurately judge his distance from the ground, trees, buildings, etc.; in low flying for the same reasons; and in formation flying, where he must keep a safe but short distance from other ships.

Regarding the factors operative in judgment of distance, there are some factors common to both monocular and binocular vision, such as terrestrial association, motion parallax, and aerial perspective, which are eliminated under test conditions. Accommodation and convergence can also be eliminated. Capt. H. J. Howard, in an article called "A Test for the Judgment of Distance," in the Transcriptions of the American Ophthalmological Society, 1919, says:

"The two remaining factors are the binocular parallax and the size of the retinal image. It is possible to obtain the relative values of these two factors by using the same test apparatus, first with two eyes and then with only one eye. In the first instance both factors may operate together; in the second instance the binocular parallax is eliminated and only the size of the retinal image can operate. This latter is practically as important a factor with one eye as it is with two. If by comparison it be found on the one hand that the results are the same or approximately the same, it is obvious that the size of the retinal image which operated in both tests is the important factor. If, on the other hand, it be found that the binocular test produces a far more delicate discrimination than the monocular, we are forced to the conclusion that the binocular parallax is the more important factor, and the size of the retinal image is negligible or practically so."

Bearing these facts in mind, we turn to the results of the depth perception tests. By averaging the ten readings for the right eye, the individual average for each subject was obtained. The same procedure was followed with the

readings for the left eye and for both eyes, and these averages were used in the calculations. The depth perception (D. P.) averages of all subjects were found to be as follows:

100 cases.	M (DP).	PEm.	Sigma.	C.
Right eye	118.30	±3.92	58.18	0.48
Left eye	118.50	±4.55	67.42	.47
Both eyes	18.65	±1.57	23.23	1.24
Sighting eye (right, 71 cases; left, 29 cases)	110.52	±4.19	62.12	.56

The great discrepancy between the average for both eyes and the average for either eye alone will be noted at once. The average judgment with the left eye is more than six times as large as the average for both eyes, and the averages for the right eye and the sighting eye are nearly as large. The mean judgments with the right and left eyes are very close, the average for the sighting eye being slightly better.

The probable error of the mean (PEm) gives the measure of unreliability of the mean and may be defined as that variation from the average which is as often exceeded as fallen short of. It is that amount which added to or subtracted from the mean gives a range within which 50 per cent of the values will fall.

Sigma is likewise a measure of variability. If on the probability curve a distance equal to sigma is laid off on either side of the mean and ordinates erected from the base line to the curve, two-thirds of the total number of measures will be found to fall in the area between the ordinates, base line, and curve. The large sigmas in this case (in one instance as large as half the distance estimated) indicate that the probable error of an individual estimate is large, and that the distribution is scattered—a large number of judgments falling wide of the average.

The variability of the different series of measurements may be directly compared by comparing their coefficients of variability (C). These coefficients indicate that the individual judgments made with the sighting eye and with the left eye are equally variable and are more variable than the judgments made with the right eye, while the judgments made with both eyes vary more widely than any of the others.

From a survey of these results it is plain, then, that in spite of the wide individual variations in judgment made with binocular vision, the average is far below that made with monocular vision.

The data were next rearranged according to the degree of visual acuity of the subjects. The average depth perception of those subjects having a visual acuity of 20/20 with each eye was obtained, and also of those subjects having a visual acuity of 20/15 with each eye. A similar average for both right and left eye was made for those subjects with a visual acuity of 20/20 and 20/15 respectively. The results of both groups are presented here for comparison.

	Cases.	M (DP)	PEm.	M dif.	Ped.	C.
Right eye 20/20	29	129.68	± 7.91	27.34	± 6.33	.48
20/15	60	102.34	± 4.74			.53
Left eye 20/20	18	151.94	±13.70	40.12	±12.78	.55
20/15	64	111.82	± 4.93			.52
Both eyes 20/20	16	28.11	± 1.96	16.09	± 1.74	.64
20/15	57	12.02	± .90			.83
All others	26	26.92	± 3.81			

One striking fact brought out by this table is that there were approximately three times as many subjects with 20/15 vision, or better, as with 20/20, although the latter is considered normal. It must be remembered, however, that the great majority examined were young men, the group average being 28.9 years. Those individuals with 20/15 vision were also better in judgments of depth perception than were the subjects having 20/20 vision, although the variability is about the same for each series of measurements. Particularly in the series for the left eye and for both eyes is this difference noticeable, indicating that the keener the vision, the more accurate would depth perception judgments tend to be. A correlation between these two factors of depth perception and visual acuity gave a result of 0.457±0.053, a figure which is more than eight times its probable error and therefore a reliable indication that there is a definite relationship between the two and that improvement in the former is associated with improvement in the latter. After applying Chauvenet's criterion to eliminate the extreme cases which were not typical of the group, the mean of depth perception was found to be 16.27±1.02, which is lower than the average formerly obtained for all cases, and the mean of visual acuity was 20/15+1, which is a high average. Inasmuch, then, as more than two-thirds of the subjects possessed a visual acuity considerably above the requirements demanded, it is evident that the degree of visual acuity considered a necessity for fliers is not excessive for the material available.

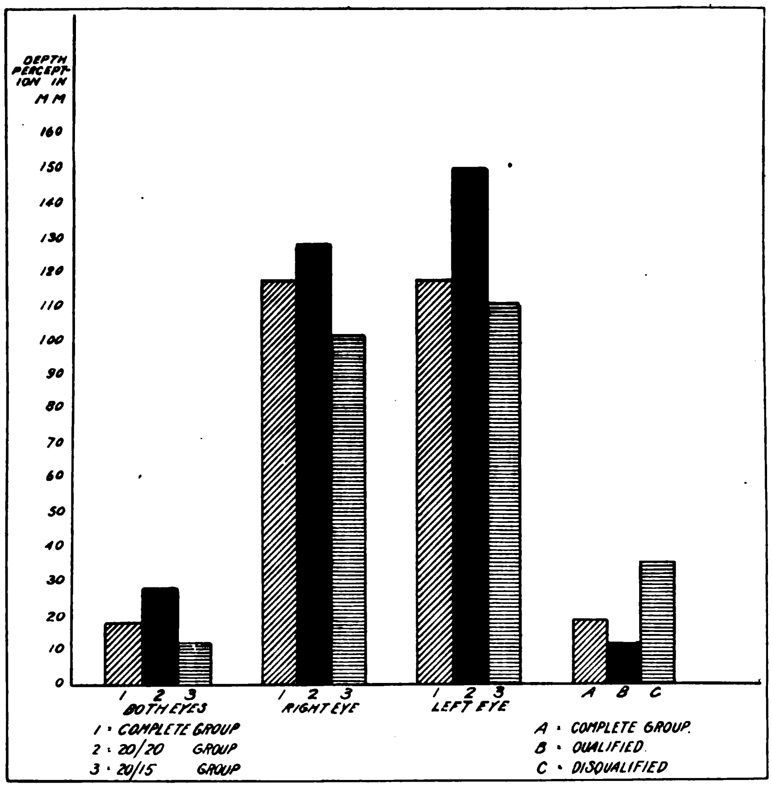
The fact that one mean is higher than another does not necessarily indicate a true difference between the means. A glance at the table of comparison shows that this difference is considerable, but the degree of reliability of that difference is determined by the size of the probable error of the difference (PEd). To determine a satisfactory degree of reliability, the difference of the means should exceed the probable error of the difference by at least three times, so it is apparent that the probable error of the difference of the means for both eyes (16.09±1.74) is particularly significant, as the difference of the means exceeds it by more than nine times.

The subjects were next divided into two groups, (1) those qualified to fly and (2) those disqualified because of poor visual acuity, low angle of convergence, muscle imbalance, color blindness, etc. The average depth perception judgments for each group were obtained and they were found to differ widely. The mean in millimeters for the qualified group was 11.93±0.52 with a coefficient of variability of 0.54 and the average for the disqualified group was 36.30±5.72 and a coefficient of variability of 1.28. As more than 30 mm. disqualifies in the depth perception test, the size of the latter average is significant. After eliminating one extreme case in this group, the average is still 29.66 mm. The results show that the subject disqualified on any ophthalmological findings is apt to have a depth perception average near the disqualifying limit and to make erratic judgments varying widely from the normal average. The qualified man, on the contrary, has an average depth perception far better than the standard requirements, and his judgments are more constant and reliable.

Of the thirty disqualified subjects, nine failed to attain the required average of 30 mm. in depth perception, but in only one of the nine cases was the failure of depth per-

ception the sole disqualifying factor. The remaining twenty-one subjects had a qualifying depth perception average but were disqualified for other causes such as paralysis of the eye muscles, poor visual acuity, more than the allowable amount of hyperphoria or esophoria in conjunction with diplopia, etc. The fact that the mean for all thirty subjects is outside the qualifying limit, and even excluding one extreme case is 29.66 mm., shows that the readings in the majority of cases are very close to the disqualifying mark. The results indicate also that inability to judge depth perception distance with a normal degree of accuracy is quite closely associated with faulty ocular function.

the all-important factor in depth perception judgment, and that the size of the retinal image which operates in monocular vision is of practically negligible importance in judgment of distance. It is plain that for accurate depth perception judgment good binocular vision is necessary, and the results of these tests show that the better the visual acuity the more exact the depth perception judgment tends to be. As the average—with both eyes—for all subjects, both qualified and disqualified, is 18.65 millimeters, it would seem that the standard which designates 30 millimeters as a minimum depth perception requirement is not too high. On the contrary, from a consideration of the average for the complete group and for



The average angle of convergence for all subjects was found to be 58.9° ±0.98, and an attempt was made to discover a possible relationship between this angle of convergence and the diopters of accommodation of the right and left eyes, but as some of the necessary data were lacking in many cases the results were wholly unreliable. This outcome was not altogether unexpected, as the readings were all taken at 20 feet.

A graphic representation of the comparison of the averages of the depth perception judgments of the two groups of subjects based upon their degree of visual acuity with the average for the complete group is presented above. The great difference in judgments of depth perception made with binocular and with monocular vision would tend to prove that it is the binocular parallax which is the qualified group, which is 11.93 millimeters, it is probable that the standard should be raised and a minimum depth perception average of 25 millimeters or 20 millimeters be required.

BIBLIOGRAPHY.

Standards of Physical Examination for Flying, pages 14–24.

Howard, Harvey J.: A Test for the Judgment of Distance. Transcriptions of the American Ophthalmological Society, 1919.

Whipple, Guy M.: Manual of Mental and Physical Tests, volume 1, chapter 3.

—By courtesy of the American Journal of Ophthalmology.

STUDIES ON THE RESPONSES OF THE CIRCULATION TO LOW OXYGEN TENSION.

V. STAGES IN THE LOSS OF FUNCTION OF THE RHYTHM PRODUCING AND THE CONDUCTON TISSUE OF THE HUMAN HEART DURING ANOXEMIA.

CHARLES W. GREENE and N. C. GILBERT, *from the Department of Physiology and Pharmacology, Laboratory of Physiology, University of Missouri and the Department of Medicine, Northwestern University School of Medicine.*

[Figures in parentheses refer to bibliography at end of article.]

That systemic asphyxiation is a factor in producing slowing of the heart rhythm and in decreasing conductivity has long been known (Klug (1), Konow and Stenbeck (2), and numerous later investigators). Our present views as to the anatomical differentiations within the heart have resulted from a series of papers presenting the morphological and physiological facts of the conducting and nodal system (Kent (3), His (4), Keith and Flack (5), DeWitt (6), Mall (7), Lhamon (8), Eyster and Meek (9), and many others). The facts of the functional control of the heart rhythm and sequence from dominant centers as understood at the present time have been developed especially by Erlanger (10), Keith and Flack (5), Adam (11), Flack (12), Lewis (13), Ganter and Zahn (14), Meek and Eyster (15), and Lewis (16). The influence of temperature, of asphyxia, of drugs, and especially of the extrinsic nerves on the sino-auricular and auriculo-ventricular rhythms and on conduction have been discussed in several of the preceding references and also by McWilliam (17), Lewis and Mathison (18), Mathison (19), Meek and Eyster (20), Eyster and Meek (21), Schlomovitz, Eyster, and Meek (22), and by Lewis, White, and Meakins (23). The reference list is not exhaustive, but the literature is fully reviewed in several of the references given. We have also briefly reviewed the literature on asphyxia in Article III of this series (24).

The electrocardiographic method has been applied to the study of the changes in the mammalian heart in numerous studies from the laboratories of the University of Wisconsin by Eyster and Meek, who used also the method of asphyxia to follow the point of origin of the pace-maker of the dying mammalian heart. In Lewis's laboratory in London, too, numerous electrocardiographic studies have tended to clarify our knowledge of the physiology both of the factors of intrinsic and extrinsic cardiac regulative control. Lewis and Mathison (18) showed that conduction and rhythm production are decreased even to the point of suspension when an animal with open chest is allowed to asphyxiate by stopping artificial respiration, and they have published electrocardiograms showing these points. Ganter and Zahn (14) and Meek and Eyster (21) found that if the sino-auricular node was cooled locally the pacemaker was driven to a lower point in the heart, i. e., the auriculo-ventricular node. This the latter proved by two leads taken directly from the exposed heart. Lewis, White, and Meakins (23) showed that the displacement was by gradual steps in some animals (the cat) and by sudden shifts in others (the dog) as shown by shortening of the P–R interval. They observed that when the rhythm arises in the A-V node the conduction may be retrograde, as indicated by the R–P interval, a new point in mammalian heart physiology. Further asphyxiation suppressed the retrograde conduction and all evidence of auricular contractions disappeared. We call attention to the experiment of Lewis, Meakins, and White on the cat, Figure 6, Plate 2, with the following legend: "After establishing A–V rhythm by applying cold continuously, a cat was asphyxiated; by the one hundred and forty-fifth second of asphyxia the heart passed through several stages of partial reversed block and finally the auricular contractions had vanished. The curve commences at this state and shows the recovery of the S–A node soon after the withdrawal of cold from it. The ventricular rate is practically unaltered and complete heart block is evidenced by the dissociation of auricular and ventricular rhythms." This figure is quoted as direct experimental proof of asphyxial suppression of auricular contractions in the mammalian heart.

In our previous papers we have shown that in men during extreme oxygen-want very marked changes may occur in the mechanism of the human heart. These critical changes for the most part did not appear until the stage of oxygen-want in which the oxygen is insufficient to maintain the nervous system in conscious activity. In other words, the more profound changes during low oxygen are imminent at the approach of unconsciousness, and of skeletal muscular collapse, though cardiac slowing and disturbance of the normal mechanism follow these events in sequence. We have published examples in which two of the chief irregularities of the human heart are loss of auricular contraction as evidenced by disappearance of the P wave, and loss of internodal conduction as indicated by dissociation. In the present paper we give in detail the reactions of an extreme case of this type, a case somewhat different but crucial as regards the nature and sequence of the local cardiac changes which we have followed without interruption.

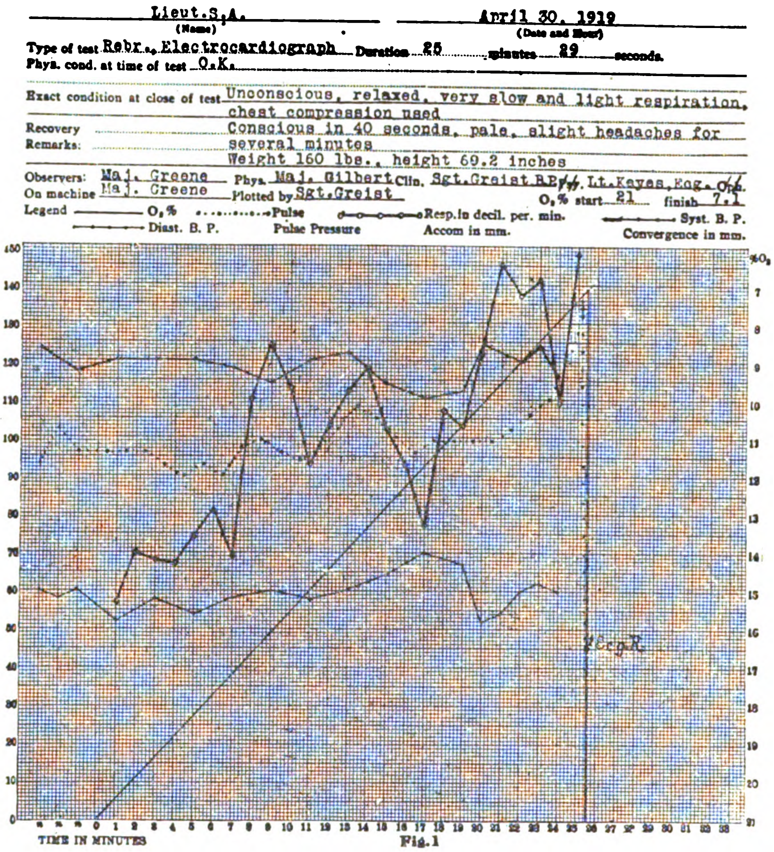


Fig. 1.—The clinical chart of Lieut. S. A. shows the heart rate, dotted line; systolic blood pressure, the top light line; diastolic blood pressure, the bottom line; respiratory minute-volumes, heavy line. The heart rates are taken by 20-seconds counts at the wrist during the first 20 minutes, and from the electrocardiogram from the 20th minute to the end of the record. The blood pressures are measured by the Rogers sphygmomanometer. The deciliters of air breathed per minute were read off the Larsen recorder. The blood pressure, heart rate, and deciliters of air are all shown by the legend to the left; oxygen percentages are indicated to the right.

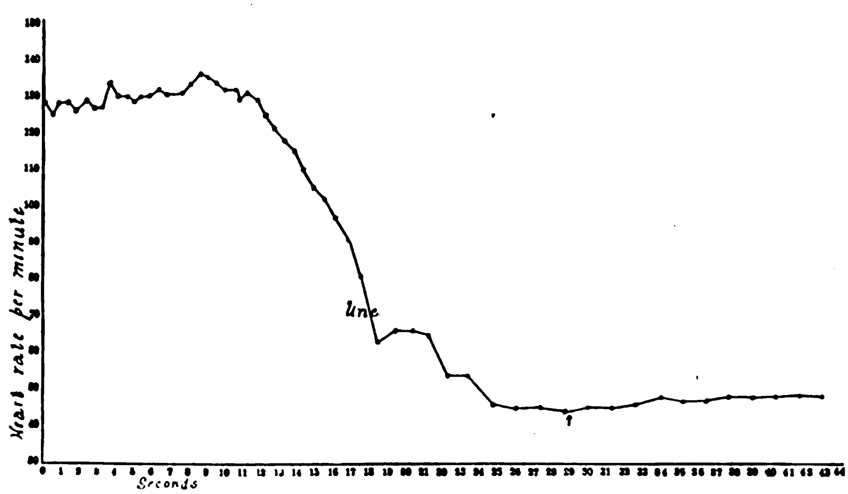


Fig. 2.—The heart rate per minute of Lieut. S. A. during the post-crisis stage of oxygen-want, calculated beat by beat, beginning with the 26th minute. *Unc*, became unconscious at about this point; *off*, removed from the test.

Table 1.—*Showing the variation in the pulse and in the electrocardiogram at intervals through the rebreather test. Time in seconds. Amplitude of the deflection in millimeters, equivalent to 10^{-4} millivolts. Lieut. S. A. April 30, 1919. Final oxygen 7.1 per cent. Time of run 25 minutes, 29 seconds. Equivalent altitude 28,000 feet.*

Trace and pulse number.	Time in minutes.	Oxygen in per cent.	Duration in seconds.			Amplitude in millimeters.				
			R-R.	P-R.	R-T.	P.	Q.	R.	S.	T.
1-10	Normal.	21.0	0.656	0.136	0.320	0.8	None.	14.0	1.0	2.4
2-4	5	18.2	0.648	0.140	0.328	1.0	None.	13.5	1.2	2.3
3-2	10	15.5	0.624	0.140	0.292	0.9	None.	15.0	1.6	1.8
4-1	15	12.7	0.640	0.152	0.312	0.9	None.	13.0	1.4	1.8
5-20	20	10.0	0.584	0.144	0.280	1.0	None.	12.0	1.5	1.6
6-122	22	9.0	0.700	0.152	0.296	1.0	None.	11.5	1.0	1.8
7-237	24	7.9	0.568	0.136	0.280	0.9	None.	12.0	1.4	1.0
8-275	25	[1]7.3	0.492	0.120	0.260	1.2	None.	9.5	1.4	1.0

[1] Circulatory break at the end, see Table 2. No recovery tracing secured.

Table 2.—*Variation in heart rate and in the electrocardiograms through the entire post-crisis stage of Lieut. S. A. The rates are computed on the basis of the length of the R-R intervals beginning at the crest of the maximum heart rate. The break occurred at 25 minutes, 10 seconds. The measurements of the P-R and R-T intervals are difficult and the factor of error is large. Lieut. S. A. April 30, 1919. Time of run 25 minutes 29 seconds. Final oxygen 7.1 per cent—28,000 feet elevation.*

Time in seconds beginning at 25 minutes.	Equivalent rate for each consecutive beat.		Electrocardiograms.			Remarks.
	Pulse number.	Rate.	P-R interval.	R-T interval.	R amplitude.	
10.00	1	132	0.13	0.26	11.5	
10.48	2	132	.13	.26	12.6	
10.90	3	129	.13	.26	12.4	
11.38	4	131	.13	.25	12.4	
11.84	5	129	.13	.27	12.6	
12.32	6	125	.13	.28	12.6	
12.80	7	121	.13	.29	13.0	
13.30	8	118	.13	.30	13.0	
13.32	9	116	.14	.31	12.4	
14.36	10	110	.13	.29	13.8	
14.96	11	105	.12	.30	14.0	
15.54	12	102	.13	.32	14.5	Muscular tremors severe
16.12	13	97	.14	—	14.0	during four beats.
16.80	14	91	.13	.33	13.4	
17.54	15	81	.12	.33	13.4	
18.48	16	63	.112	.33	13.0	P inverted.
19.36	17	66	.098	.31	13.6	Do.
20.28	18	66	.094	.30	13.0	Do.
21.18	19	65	.10	.30	14.6	Do.
22.30	20	54	.10	.34	14.0	Do.
23.40	21	54	.10	.30	16.0	Do.
24.68	22	46	.10	.31	16.0	Do.
26.04	23	45	.17	.35	22.6	R-P or reversed conduction
27.36	24	45	.21	.33	22.3	the P still inverted.
28.72	25	44	.23	.34	21.5	"Off" here.
30.04	26	45	None.	?	18.4	No P waves during the 10 re-
31.26	27	45	None.	?	16.5	corded beats of this stage.
32.68	28	46	None.	?	19.0	
34.00	29	48	None.	?	18.0	
35.28	30	47	None.	?	19.4	
36.58	31	47	None.	?	18.0	
37.82	32	48	None.	?	16.5	

Lieut. S. A. was carried to the stage of unconsciousness in an altitude test by the rebreather method, the procedure being the same as used in our previous research. Electrocardiograms were obtained at 5-minute intervals to 20 minutes, then a continuous electrocardiogram was recorded for the last 6 minutes and to the close of the test. The graph representing clinical progress of the entire test is shown in Figure 1. The general electrocardiograpihc changes throughout the test are given in Table 1. The heart rates calculated on the basis of the time of the successive cycles from a moment before the maximum heart rate through the terminal fall in rate to the end of the test are shown in Figure 2. The electrocardiographic data for the critical post-crisis period is presented in Table 2. The electrocardiograms representing the successive stages of the test are reproduced in Plate 1, Figures 1 to 8.

The general changes during the development of low oxygen are not essentially different from the types previously described. Lieut. S. A. follows the rule during the precrisis stage, both in the clinical cardio-vascular responses and in the changes shown by the electrocardiograms. The heart accelerated to 136 at the crisis, but with considerable variation in time of cycles between the twelfth and seventeenth minutes. The systolic pressure fell during the thirteenth to eighteenth minutes, which, taken with the rise in diastolic pressure, the change in heart rate and the fall in respiratory volume, indicates a failure to adequately respond to the strain at this period. He rallied and continued to compensate until the twenty-third minute and became unconscious in the twenty-fifth minute. These irregularities of compensation characterize nervousness during the test rather than weakness under the test. However, the test was made to the extreme limits and thus revealed vital and illuminating post-crisis changes in the heart.

Unconsciousness supervened at the point marked *Unc* in the electrocardiographic record, Figure 8. He was continued in the test until his muscles began to relax, i. e., 10 seconds after the evidence of unconsciousness, and was then rapidly removed from the rebreather. Skeletal muscle relaxation became complete during the removal of the mouthpiece, and relaxation continued to the end of the cardiographic record. His respirations at this time were very shallow and faint. Artificial respiration by compression of the thorax was produced at this point. Unfortunately at this critical time the electrocardiographic apparatus became disconnected so that the transitional stages toward cardiac recovery were not recorded. He remained unconscious about 40 seconds, then quickly and suddenly regained consciousness and muscular control. He was a little pale, was not nauseated, suffered some slight headache for several minutes, but otherwise showed no deleterious aftereffects from the experience.

Both the clinical determinations and the heart rates obtained from the electrocardiograms show early progressive acceleration of the heart. This reaction is usually given by a normal compensator during the early and precrisis stages of the altitude test. The heart rate augmented from the rather high initial rate of 90 to a maximum of 136 per minute at the crisis at the beginning of the twenty-fifth minute. At this time the rate began to decrease, at first slowly through 6 or 7 beats, then very rapidly until the low rate of 44 per minute was reached when the test was terminated. The beats remained at the slow rate for the remaining 10 seconds recorded.

The electrocardiogram taken continuously from the twentieth minute, therefore including the time from the moment of maximum heart rate through the entire terminal or postcrisis period, shows in continuous panorama the facts on which we base the interpretation of the

extreme effects of low oxygen on the behavior of the normal human heart. We emphasize above all the eivdence that oxygen deficiency does not become vital to the heart itself until late, certainly not before the onset of unconsciousness. But when the crisis is reached the postcrisis changes occur rapidly, indeed in a few seconds.

The graph, Figure 2, and the electrocardiogram, figures 8 and 9 of plate I, show that during 20 consecutive beats the rate dropped from 136 to 44 per minute. The rate was 100 at the beginning of a group of 4 contractions complicated in the electrocardiographic record by skeletal muscular tremors. Unconsciousness occurred during this period, according to the clinical evidence on which we base judgment. Lieut. S. A. did not immediately lose reflex contol of his muscles, and still held the mouthpiece safely for a few seconds longer. The rate was 81 at the inversion of the P and the onset of unconsciousness and 66 at its consummation.

observed by Ganton and Zahn, and by Meek and Eyster. The inverted P exists through seven successive contractions, though the third contraction does not show the phenomenon clearly. In these seven beats the P wave precedes the R by a very uniform but shortened time interval.

On the third beat before the close of the test the P wave suddenly shifts to a post R position with a relatively long R-P interval. The last beat of the three in which this condition exists occurs at the moment of taking "off." Each successive R-P interval is longer, 0.17, 0.21, and 0.28 second, signifying the progressive and rapid loss of reverse conduction. This group of contractions indicates the shift of the rhythmic center to a still lower or third point of origin, presumably low in the A-V node. The sequence is reversed and condution is back to the auricle. At this moment the rate is at its slowest—i. e., 44 to 45 per minute—where it remains with little variation during the last 10 beats recorded.

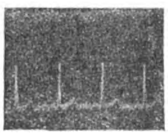


FIG. 1.
Normal, pure air.

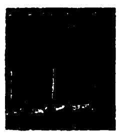


FIG. 2.
18.2 oxygen.

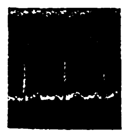


FIG. 3.
15.5 oxygen.

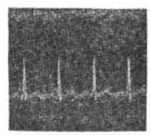


FIG. 4.
12.7 oxygen.

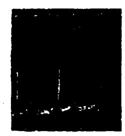


FIG. 5.
10.0 oxygen.

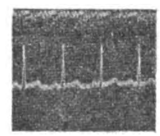


FIG. 6.
8.9 oxygen.

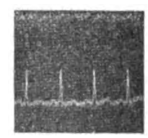


FIG. 7.
7.8 oxygen.

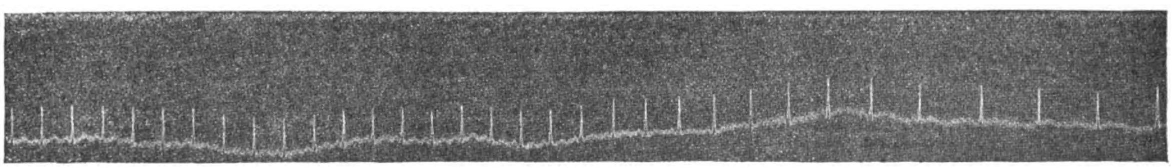


FIG. 8.—7.2 oxygen.

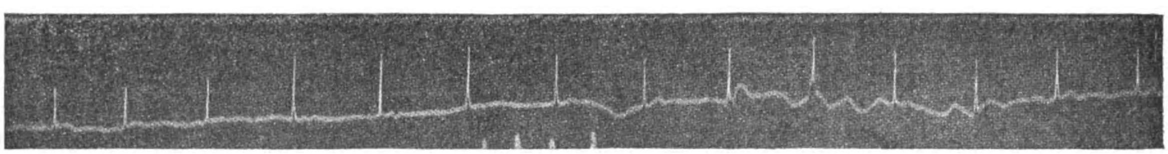


FIG. 9.—Continuation of figure 8.

PLATE I.—Responses to circulation of low oxygen test.

PLATE I.—The electrocardiogram of Lieut. S. A.; Figure 1, normal; Figure 2, after 5 minutes; Figure 3, 10 minutes; Figure 4, 15 minutes; Figure 5, 20 minutes; Figure 6, 22 minutes; Figure 7, 24 minutes; Figure 8, begins at 26 minutes and 10 seconds; Figure 9, continuation of Figure 8. The four shadows on Figure 8 and the word *off* mark the point when Lieut. A. was taken off the test. The changes in heart rate in Figures 8 and 9 are shown graphically in text Figure 2. Time in fifth seconds. The R deflections of the original record have been strengthened by the engraver in reproducing the plate.

An inverted P wave appears during the last heart beat of the group in which skeletal muscular contractions occurred. This beat is coincident with a decided slowing in the rate, from 102 just preceding the unconscious stage to 64 during this beat. There is also a sudden reduction in the P-R interval showing that the time of conduction from the new source of the beat to the ventricular tissue is reduced, from 0.127 to 0.098 second. (See Table 2.) Inversion of the P wave and shortening of the P-R interval are interpreted as signifying origin of the rhythm lower down in the system—i. e., the S-A node—or at least as low as the coronary sinus portion of the A-V node, as indicated in certain displacements

Augmentation in the amplitude of the R wave takes place at the time when the P shifts to the post R position. We offer no obvious explanation for this fact other than that the ventricle beats first in sequence; i. e., is the primary activity. During the last 10 beats the amplitude of the R varies little or none from beat to beat. The irregularity of the record from extrinsic currents confuses the R-S-T amplitudes to a degree.

The steps in the transition of the P outlined above indicate the suppression of the successive pace making foci. The normal S-A node first succumbs during asphyxiation. The first ectopic rhythmic focus next ceases to function. There is finally left a rhythmic center well

down in the conducting system adequate to maintain rhythm. It is true the rhythm is at a greatly reduced rate, although the reduction is not so great as that often observed in pathological heart block.

At the moment of closing the experiment the P wave disappeared entirely. It did not reappear during the ten ventricular complexes of the remainder of the record. This we interpret as suppression of function of the conducting tissue sufficient to block conduction from the lower rhythmic center back to the auricle, demonstrating for man the additional new point that anoxemia blocks retrograde conduction from the ventricle toward the auricle during A-V rhythm. This was first shown to be true during systemic asphyxiation by the method of stopping respiration in lower animals, by Lewis, White, and Meakins, who of course were dealing with excess of carbon dioxide as well as lack of oxygen. All the remaining contractions are normal ventricular complexes of the type in which the beat arises in the conducting system rather than in the muscle. No ectopic beats occurred in this case.

There is only the merest suggestion of an increase in rhythm during the ten beats that occur without auricular beats; in fact the rate is slow and remarkably regular from the moment the first R-P interval occurs.

This record gives conclusive evidence from the human subject that the pace-making function in the heart is depressed and lost in the descending direction during anoxemia induced by the rebreather method. The evidence from mammalian experimental sources is confirmed for the human. The most sensitive parts of the conducting system are the S–A node and the internodal region. These are both rendered inactive by oxygen-want long before rhythm and conduction are lost in the A-V node and the peripheral parts of the system. We believe these changes are immediately due to vago-spasm. But whether one accepts the explanation of vagal stimulation or of direct asphyxial effects, it is obvious that when for any reason, either physiological or pathological, the S-A pace-making center ceases to function and the auricular or internodal paths cease to conduct, thus suppressing auricular contractions, then the basic rhythmic property of the A-V node still persists to control the contractions of the ventricle for a time until the crisis passes. This control proceeds from the A-V node over the ventricle, and the rate, though slow, is adequate for a circulation of considerable efficiency. These observations agree with the deductions made in our previous paper. They confirm for man the facts pointed out by Meek and Eyster (20) for the dog, i. e., that the heart is sensitive to extrinsic control in the descending direction and "that the specialized tissues of the heart exhibit from above downward progressively diminishing degrees of automaticity."

The case of Lieut. S. A. differs from the others reported by us in that the shift of the point of origin of the rhythm and the loss of internodal conduction is by relatively sudden steps, rather than by progressive displacement of the pace-maker and of conduction.

The facts observed in our case are clear-cut and definite and we recognize that the practical significance in aviation and in clinical medicine is definite and clear. The slowing of the rhythm, inversion of the sequence to ventricle-auricle beats, and finally the decrease and disappearance of auriculo-ventricular conduction are all changes perfectly characteristic of over activity of the vagus center. This human case might be explained on the basis of Mathicon's observations of mammalian asphyxial vago-spasm. Wilson has chown that the S-A node is particularly sensitive to vagal control in man both in the normal (26) and in the stimulative stage of the action of atropine (27). Vagus action not only changes auricular rate but lowers auricular intensity, as shown by decrease in amplitude of the P. Change in amplitude of the P was not observed in Lieut. S. A. The P was inverted—not the usual type of vagus effect. The ventricular rate is most constant. In view of the evidence of direct vagal inhibitory influence over the A-V nodal rhythm, the failure of further ventricular slowing during the extreme anoxemia needs explanation on the vago-spasm hypothesis. However, we believe that the vagus stimulation hypothesis offers the most convincing explanation and is confirmed by this human case.

In the meantime we have in progress comparative experiments on mammals based on the rebreather-electro-cardiographic methods which we hope will throw further light on the nature of the final post-crisis reactions of progressive oxygen-want as observed in man.

In closing this paper we again emphasize the numerous parallels we have observed in the physiology of the normal nodal system of the human heart in comparison with the facts of cardiography established on experimental animals. We also emphasize the correspondence as between simple anoxemia and the symptom complex of asphyxial cessation of breathing when excess of carbon dioxide is added to anoxemia.

SUMMARY.

An additional and extreme case of oxygen deficiency on the normal human subject showing changes in the heart during a rebreather test is presented with continuous electrocardiograms through the crisis and post-crisis periods. The data show:

1. That reflex muscular control in the human may persist 6 to 8 seconds after loss of consciousness from anoxemia.

2. That sino-auricular rhythm is lost by steps; first to a lower point in the sino-auricular system; second, to a point nearer the base of the ventricle, presumably the auriculo-ventricular node.

3. That internodal conduction is finally lost, a brief stage of reversed conduction terminating in lengthening R-P intervals precedes total loss of conduction.

4. That the ventricular rhythm is very persistent and unexpectedly regular during the late postcrisis stage. In this case the equivalent rates are from 63 to 44, increasing to 48 per minute in 10 seconds after removal of the mouthpiece.

5. That in man lack of oxygen induces a series of changes in cardiac rhythm, in conduction and in suppression of auricular contractions quite parallel to similar phenomena established in experimental animals under general asphyxiation.

BIBLIOGRAPHY.

(1) Klug: Arch. f. Anat. u. Physiol., Physiol. Abth., 1883, 394.
(2) Konow and Stenbeck: Skand. Arch. f. Physiol., 1889, i, 403.
(3) Kent: Journ. Physiol., 1893, xiv, 233.
(4) His: Abhandl. d. Sachs. Ges. d. Wiss. Math.-Physik.-Kl., 1893, xix, 1; Zentral. f. Physiol. 1895, ix, 469.
(5) Keith and Flack: Journ. Anat. and Physiol., 1907, xli, 172.
(6) DeWitt: Anat. Record, 1909, iii, 475.
(7) Mall: Amer. Journ. Anat., 1912, xiii, 249.
(8) Lhamon: Amer. Journ. Anat., 1912, xiii, 55.
(9) Eyster and Meek: Heart, 1914, v, 119.
(10) Erlanger: Zentralbl. f. Physiol., 1905, xix, 9; Journ. Exper. Med., 1905, vii, 51; 1906, viii, 8.
(11) Adam: Arch. f. d. ges. Physiol., 1906, cxi, 607.
(12) Flack: Journ. Physiol., 1910, xli, 64.
(13) Lewis: Heart, 1910, ii, 23.
(14) Ganter and Zahn: Zentralbl. f. Physiol., 1911, xxv 782; Arch. f. d. Gesammt. Physiol., 1912, cxxxxv, 335.
(15) Meek and Eyster: Heart, 1914, v, 227.
(16) Lewis: Heart, 1914, v, 247.
(17) McWilliam: Journ. Physiol., 1888, ix, 167.
(18) Lewis and Mathison: Heart, 1910, ii, 47.
(19) Mathison: Heart, 1910, ii, 54.
(20) Meek and Eyster: This Journal, 1914, xxxiv, 368.
(21) Eyster and Meek: Heart, 1914, v, 137.
(22) Schlomovitz, Eyster and Meek: This Journal, 1915, xxxvii, 177.
(23) Lewis, White and Meakins: Heart, 1914, v, 289.
(24) Greene and Gilbert: Arch. Inter. Med., 1921, xxvii, 517.
(25) Lewis: Mechanism and graphic registration of the heartbeat. Hoeber, New York, 1920.
(26) Wilson: Arch. Inter. Med., 1915, xvi, 86.
(27) Wilson: Arch. Inter. Med., 1915, xvi, 989.

By courtesy of the American Journal of Physiology.

STUDIES ON THE RESPONSES OF THE CIRCULATION TO LOW OXYGEN TENSION

VI. THE CAUSE OF THE CHANGES OBSERVED IN THE HEART DURING EXTREME ANOXEMIA[1]

Chas. W. Greene and N. C. Gilbert, *from the Department of Physiology and Pharmacology, Laboratory of Physiology, University of Missouri, and the Department of Medicine, Northwestern University School of Medicine*

[Figures in parentheses refer to bibliography at end of articles.]

In our previous papers we have presented the changes that occur in the human during extreme anoxemia with especial reference to cardiac physiology. In our rebreather method the carbon dioxide is absorbed by shell caustic potash, hence there is no increase in carbon dioxide of the inclosed air during the augmentation of respiratory volume. In fact there may be a decrease in carbon dioxide due to the overventilation of the lungs with the consequent lowering of carbon dioxide tension in the body. Therefore, the gradual reduction of oxygen in the air breathed, hence in the lungs and body tissues, may be considered as the primary cause of the physiological changes observed. The condition is a true anoxemia. We have already reviewed at some length the literature of this subject, especially that developed in connection with the work of the Medical Research Laboratory of the Air Service (1), where we first began the investigation of this problem on man.

In preceding papers of this series (2) we described the late cardiac effects of anoxemia when the condition is pushed beyond the ordinary limits of the technical air service examination. What we have described as the post-crisis stage includes the changes observed in the circulatory system and especially in the heart after unconsciousness has occurred. These changes in the heart of man are summarized as follows:

1. Progressive suppression of the S-A rhythm in the descending direction to the vanishing point.
2. Establishment and persistence of the A-V rhythm with its characteristic slow and regular rate.
3. Decrease in conduction in the internodal region to the point of suppression.
4. Reversed rhythm and reversed internodal conduction.
5. Auricular pause after reversed conduction disappears.
6. These changes obey the laws of cardiac nervous control of rhythm and conduction, as outlined by Eyster and Meek.
7. Rapid recovery from all these disturbances (i.e., within a few seconds) when the man is allowed to breathe fresh air.

Most of these phenomena had been described in labortory animals under the condition of systemic asphyxiation, but not in man. Eyster and Meek (3) especially have advocated the view that the phenomena are primarily due to vagospasm. Others, especially those working in Lewis's laboratory, have emphasized the fact that the asphyxial stress on the heart also acts directly on cardiac tissue. In all the earlier experiments on animals two factors are involved—oxygen want and carbon dioxide excess. Mathison (4) alone has tried to separate these factors by allowing his animals to breathe pure nitrogen, thus getting rid of the carbon dioxide by excessive ventilation. He concludes that "want of oxygen * * * alone is responsible for the production of block." He says also: "The heart block is undoubtedly due to the effect of want of oxygen on the cardiac tissues." Mathison describes stimulation of the cardio-inhibitory center, especially after chloroform, but he closes his article with the sentence: "Heart-block appears to be a regular occurrence during asphyxia in dogs in which the vagi are cut. When the vagi are intact, permanent cardiac inhibition frequently comes on before heart-block can appear."

These quotations summarize the most direct evidence bearing on our problem that we have been able to find. There is nothing in the literature that deals directly with man which furnishes an experimental basis for analyzing the mechanism involved in the observations which we have reported.

Lutz and Schneider (5) studied the responses of men breathing pure nitrogen from a Larsen spirometer supplied from a gas bag and exhaling into outside air. By this method they produced acute anoxemia in a few seconds. They obtained cardiac acceleration in from 5 to 55 seconds, "within 15 seconds in 60 per cent of the cases." While they obtained unconsciousness in certain tests they record no heart rates at this stage, in fact, resupplied air and studied the return phenomena before the extreme anoxemia with which we are concerned had appeared. For the purposes of our experiments such methods are too acute and do not allow full adjustment of the tissues to the external conditions. The same questions hold with this work as with that of Mathison on dogs.

[1] A grant in aid of this research was made from the Patton Research Fund of the Northwestern University for which appreciation is expressed.

We also express our obligations to Prof. Frank G. Becht for the many courtesies extended by the department of physiology, of the Northwestern University School of Medicine, and for generous personal assistance.

We have not tried extreme anoxemia during atropinization, in fact we have had some hesitation in using this, the only method available for answering the question whether anoxemia in man produces the observed cardiac changes by direct action on the heart and its intrinsic mechanisms, or by changes in the extrinsic nervous apparatus, i. e., primarily by vagospasm. We have interpreted our human results as due to the latter phenomenon. But we have not deemed it advisable to perform the crucial tests on man without further experimental data from lower animals.

In the present paper, dogs are used as experimental materials. A further attempt is made to determine observational facts on which to base an answer to the questions stated above.

METHOD.

Dogs have been used exclusively during this series of experiments. Anoxemia has been induced after chloretone anesthesia either alone or combined with ether. We have used the rebreather method, constructing an apparatus of small size suited to animals of about 7 to 10 kilos body weight. Changes in the general blood pressure have been measured by a mercury manometer, taking the pressure from the carotid artery. Respiratory rate was recorded by the movements of the spirometer, which also recorded, though with a low percentage of accuracy, the relative tidal volume. This apparatus records the progressive changes in volume of the inclosed air, thus giving a measure of the variations in rate and amount of oxygen consumed.

Electrocardiograms were taken at intervals of about four minutes beginning with the normal. A continuous electrocardiogram was taken from a late moment in the precrisis stage through the entire post-crisis stage and till the ending of the experiment by death of the animal, or by recovery following artificial respiration.

An analysis of the inclosed air in the rebreather chamber was made at the close of the experiment. The Haldane apparatus and method were used. The sample of air analyzed was taken from the inhalent tube, in the attempt to measure the composition of the air used by the animal at the last inhalation before respiratory failure. This doubtless gives a somewhat higher figure than the average gas content of the entire rebreather apparatus. It is recognized that the alveolar air oxygen tension is slightly lower than that found by analysis of the air from the intake tube.

Chloretone anesthesia was used to render the animal immobile. Three-tenths of a gram of chloretone in oil per kilo of body weight was injected into the abdominal cavity. Animals vary slightly in their sensitiveness to chloretone. Occasionally a second small injection was required to produce sufficiently deep anesthesia. The 0.3 gram per kilo dose, however, produces complete unconsciousness in about 10 minutes. Chloretone in excessive doses somewhat depresses the medullary centers, but the reactions of the animal to anoxemia are qualitatively normal. We have used ether anesthesia, also chloretone-ether, but we are confident that the use of chloretone alone is without error.

EXPERIMENTAL DATA.

Progressive anoxemia has been used on twenty-one animals, a total of 41 experimental tests, to determine the course of physiological events. After anoxemia is pushed to the stage of suppression of the respiratory movements there still remains a considerable interval during which artificial respiration quickly revives the animal. Revival permits several tests on the same dog. Since our primary purpose has been to determine the mechanism of the effects of anoxemia expressed by changes in the heart, we have made the tests in four groups: 1, with the vagi intact; 2, with both vagi cut; 3, after atropine; and 4, with the vagi cut at the moment when advanced responses are in progress in the heart.

ANOXEMIA WITH THE VAGI INTACT.

The dog under chloretone and with intact vagi gives a cycle of changes in response to progressive anoxemia that is characteristic and qualitatively constant. In all essential respects the physiological changes observed are very similar to those observed in man up to the stage when, in man, the tests are terminated. In the experiments recorded here the tests were carried to a much greater extreme. The changes observed in 16 experiments on intact animals which we stress are first, in the respiratory rate and tidal volume; second, the rate of oxygen consumption; third, the blood pressure; fourth, the heart rate and sequence.

THE RESPIRATORY RATE AND TIDAL VOLUME.

The changes in respiratory rate and volume during general asphyxia in man and animals have been presented in an extensive literature. The more recent papers that present aspects of anoxemial asphyxia are those from the experiments of Hough (6), Mathison (4), Gasser and Loevenhart (7), the reports of Lutz, Gregg, and Schneider (8), Ellis (9), Greene (10), from the Air Service data, and Haggard (11). The literature is more fully reviewed in these latter papers.

The experimental data concerning the respiratory responses of the dog to progressively induced low oxygen are in a manuscript in a paper by the senior author (12), but we abstract by permission from the summary of that paper:

"Chloretonized dogs during the rebreather test show the following panoramic changes in respiratory rate and amplitude. The sequence is more sure when the cycle is completed in from 15 to 18 minutes.

"1. There is little change in either the rate or amplitude of respirations in the early part of the anoxemial test, i. e., in the first 50 to 60 per cent of the duration of the test.

"2. The amplitude and tidal volume steadily increase during the last half of the test and until the respiratory crisis is reached.

"3. The respiratory rate also increases but becomes more and more irregular as the crisis is approached.

"4. The rate and amplitude both rapidly decrease during the post-crisis until within a few seconds all movement ceases.

"5. The rate of oxygen consumption was remarkably uniform to the approach of the crisis when it progressively decreased until all respirations ceased."

The dog endures a surprisingly low oxygen, as a glance at our tables will show. The average of all the acceptable tests is 3.26 per cent. The extremes vary from 4.9 to 1.6 per cent. The highest content of oxygen of air that supported respiratory movements in the dog is well below the limits that produce respiratory stress and failure in the few

extreme cases we obtained with men. Only one man of our series, Lieut. S. A. (13), certainly reached the limit of respiratory pause. His residual oxygen in the rebreather was 7.1 per cent. Others, in light of our more recent experiments on dogs, were undoubtedly just short of the point of respiratory failure when removed from the test. The evidence is found in the cardiographic records.

The rate of oxygen consumption, which of course varies with the size of the animal according to the surface area, is very uniform up to the moment of the onset of the respiratory crisis. From this point until the respirations cease the rate of oxygen consumption progressively diminishes. (See experiments 38 and 41, figs. 24 and 34.) Following the last respiration the base line usually falls somewhat in the record. (See experiment 38, fig. 23.) The explanation is that when the dog stops breathing the muscles relax and the chest volume decreases, forcing some of its alveolar air into the rebreather apparatus. When the respirations cease the tracheal tube is clamped off from the rebreather and the rebreather air then analyzed. The analyses therefore represent the percentage of oxygen in inspired air that just fails of maintaining respirations.

TABLE 1.—*Showing the entire group of experiments of the series. Chloretone anesthesia was produced by injecting a saturated warmed solution in oil into the peritoneal cavity. To the volume of air recorded for the rebreather must be added the volume of the dead space of the apparatus, about 1,100 cc., and the air of the respiratory passages. Carbon dioxide was not always perfectly absorbed in the earlier experiments.*

Date.	Experiment.	Dog.	Weight.	Chloretone per kilo.	Respirations stopped.	Air at beginning.	Air at end.	Oxygen reached.	CO_2.	Vagi cut or intact.	Electrocardiograms.
1920.			*Kgm.*	*Grams.*	′ ″	*Liters.*	*Liters.*	*Per cent.*	*Per cent.*		
May 20	1	1	....	None.	....	6.0	....	....	....	Intact	No.
Do	1	1	....	None.	15 00	6.0	[1] 3.37	2.44	....	...do	No.
May 21	3	1	....	None.	10 00	5.0	....	4.4	....	...do	No.
Do	4	2	....	None.	....	5.0	....	6.1	....	...do	No.
May 22	5	1	....	None.	14 00	6.0	[1] 3.75	2.7	0.02	...do	No.
May 24	6	3	11.4	0.3	17 15	6.0	4.5	3.83	....	...do	No.
Do	7	3	11.4	.3	14 30	5.0	3.9	....	....	...do	No.
Do	8	3	11.4	.3	17 00	5.0	3.87	3.62	.45	Cut	No.
May 25	9	5	....	.3	21 50	5.0	3.9	3.82	.10	Intact	No.
Do	10	5	....	.3	19 20	4.0	3.12	3.71	1.65	Cut	No.
Do	11	5	....	.3	19 45	3.0	2.37	3.11	2.66	...do	No.
May 26	12	6	20.0	.3	11 12	6.0	4.8	4.09	4.00	Intact	Yes.
May 27	13	7	13.0	.4	14 00	4.0	3.05	2.58	.68	...do	Yes.
Do	14	7	13.0	.4	5 00	([2])	([2])	1.6	.09	Cut	No.
Do	15	7	13.0	.4	13 42	4.0	....	4.06	1.5	...do	No.
Do	16	7	13.0	.3	10 48	4.0	3.15	3.05	1.48	...do	No.
May 28	17	8	11.4	[3] .2	13 00	4.0	3.15	2.59	1.63	Intact	Yes.
Do	18	8	11.4	[3] .2	12 15	3.0	....	2.76	.93	...do	Yes.
May 29	19	9	9.0	.3	15 20	4.0	3.25	4.46	.43	...do	Yes.
Do	20	9	9.0	.3	....	3.0	....	4.44	Trace.	...do	Yes.
June 4	22	11	10.0	.3	15 00	3.0	2.2	3.27	None.	...do	Yes.
Do	23	11	10.0	.3	10 15	3.0	2.25	2.34	....	Cut at crisis.	
Do	24	11	10.0	.3	([2])	([2])	....	1.87	None.	Cut	Yes.
June 5	25	12	10.0	.3	14 15	4.0	3.05	5.02	1.04	Intact	Yes.
Do	26	12	10.0	.3	13 30	3.0	2.3	5.19	.46	...do	Yes.
Do	27	12	10.0	.3	15 20	3.0	2.37	5.52	1.37	Cut	Yes.
Do	28	12	10.0	.3	16 05	3.0	2.3	....	....	...do	Yes.
June 10	29	13	9.0	.3	14 00	3.0	2.07	2.2	None.	Intact	Yes.
Do	30	14	9.0	.3	8 20	3.0	2.2	4.27	....	...do	Yes.
Do	31	14	9.0	.3	7 30	4.0	3.22	5.46	....	Atrop	Yes.
June 11	32	15	8.0	.3	15 30	3.0	2.2	4.17	Trace.	Intact	Yes.
June 12	33	16	7.5	.3	12 20	3.0	2.32	4.37	Trace.	...do	Yes.
Do	34	17	10.0	[3] .3	16 15	4.0	3.05	2.94	Trace.	...do	Yes.
Do	35	17	10.0	.3	13 42	3.5	2.65	2.87	None.	Cut	Yes.
June 14	36	18	10.0	[3] .3	10 25	3.5	2.42	3.46	Trace.	...do	Yes.
Do	37	19	9.0	.3	18 30	3.5	2.5	2.43	....	Intact	No.
Do	38	19	9.0	.3	14 30	3.0	2.2	2.38	....	...do	No.
Do	39	19	9.0	.3	([2])	([2])	....	2.2	....	...do	No.
June 15	40	20	16.0	.3	8 51	4.0	3.25	2.5	....	...do	Yes.
Do	41	21	19.0	.3	11 00	4.0	2.92	1.8	.10	Cut	Yes.

[1] The trial face mask used probably leaked on expiration. [2] Short special test. [3] Ether.

EFFECTS OF ANOXEMIA ON BLOOD PRESSURE AND ON THE HEART RATE.

Both the blood pressure and the heart rate respond typically and with fair constancy to anoxemia. The rebreather method, with the taking up of carbon dioxide by the potash cartridge absorption, induces anoxemia so gradually and evenly that the conditions can be repeated with great accuracy. The experimental cycle of changes constantly recur with only very minor variations.

BLOOD PRESSURE CHANGES IN THE INTACT ANIMAL.

Blood pressure remains remarkably constant for the first half or two-thirds of a rebreather test on the dog. This is shown very well in experiment 38 with the vagi intact. In this test there was little or no change in the blood pressure for the first 10 minutes of a 16-minute experiment. Beginning at about 10 minutes, the blood pressure very slowly increased through 2 or more minutes, then more and more rapidly until the maximum was reached at the time of the vascular crisis. This crisis coincided very nearly with the respiratory crisis.

Sometimes the maximal blood pressure lags a few seconds after the respiratory failure. The absolute rise in blood pressure varies in different experiments. It may amount to as much as 40 or 50 per cent of the initial pressure. (See experiment 41.) Occasionally the rise in pressure is only slight. In all cases it occurs at the extreme stage of anoxemia. The rise in blood pressure is accompanied by an increase in pulse pressure. This change is never so great in the dog but that the diastolic phase, or minimal pressure, is as great or greater than the normal. In man

the diastolic pressure seldom increases to any appreciable degree during an official rebreather test, but it always falls rapidly near its close if the test reaches the limit of compensation.

Events occur very rapidly in the circulatory postcrisis. The salient events are progressive slowing of the heart and gradual lowering of blood pressure early in the collapse, followed by a rapid fall in both rate and pressure later. (See experiment 41.)

In the crisis and during the postcrisis stages blood pressure undergoes greater and more rapid variations. The rule is that the pressure very gradually falls during the postcrisis and until the respirations cease. The heart slows down during this phase and the pulse amplitudes increase. Consequently the diastolic pressure falls rapidly while the stysolic pressure is maintained or may even rise. The maximal systolic pressure of this cycle is usually not reached until 20 to 40 seconds after respirations cease. The pessure events just described are followed by progressive and rapid decrease of both systolic and diastolic pressures with decrease in pulse rates until the pulse can no longer be distinguished and the pressure remains constant at about 15 to 20 mm. Hg. The length of time required for the entire postcrisis cycle is from 3 to 5 or more minutes after respirations cease.

Simple artificial respiration or insufflation suffices quickly to resuscitate an animal during the time when the pulse is still distinguishable on the manometric record. Later than this additional measures must be employed. Recovery of both heart rate and blood pressure when they occur are prompt, i. e., within 10 or 15 seconds.

The comparison between our results and those obtained by the methods of rapid deprivation of oxygen as practiced by Mathison (4) and by Lutz and Schneider (5) is rendered difficult, because in such experiments the results are brought on by immediate and rapid asphyxiation, i. e., within a few seconds. Mathison produced asphyxiation in his animals by stopping artificial respiration, and by using nitrogen gas with or without a minimal amount of oxygen, 1 to 2 per cent. In either case the transition from normal air to the asphyxial condition is sharp and abrupt. Schneider and Lutz had men rebreathe nitrogen gas into a small bag. Our animals are allowed 10 to 18 minutes to gradually exhaust the oxygen from the air they rebreathe. There is adequate time for slow and gradual adaptation.

When natural respirations stop it can be assumed that the tissues are already deprived of their free oxygen. The low oxygen content of the last inhaled air is the basis of this deduction. In anoxemia there is not such an abrupt and violent response in blood pressure as was obtained by Mathison. On the other hand, the rise in blood pressure is very gradual, generally uniform, and passes away with the same progressive type of readjustment.

BLOOD PRESSURE CHANGES WHEN THE VAGI ARE CUT.

If anoxemia is induced after both vagi have been cut the blood pressure runs a course qualitatively very like that in the intact animal. The variations are chiefly those conditioned by changes in heart rate and pulse pressure. The detailed picture is as follows:

The average blood pressure does not vary during the early part of the test as much as in the intact animal. But as stress from oxygen-want becomes more acute the blood pressure rises as in the normal animal. The rise progressively increases to a maximum at the anoxemial crisis. Very little difference exists in either the rate of time of development of the crisis. The type change is shown in the last part of figure 34.

After respirations cease, sometimes a little earlier, the blood pressure slowly declines through 40 to 60 seconds. It then may show a slight increase, but finally falls rapidly through 2 or 3 minutes, then more slowly for 1 or 2 minutes more until the positive pressure of 15 to 20 millimeters Hg. is reached.

If both vagi are cut the anoxemial curve of the dog never shows the enormous variations of pulse pressure during the early post-crisis stages. The response is in sharp contrast with the responses when these nerves are intact. We have never obtained confirmation of the lowered but sustained blood pressure associated with the slow heart rate, large pulse amplitude and heart block as given for the cat with the vagi cut in Mathison's experiments (see his fig. 5) (4). In dogs with vagi cut the final stages of anoxemial heart block have never appeared until the pressure approached equilibrium and the heart beats were no longer recorded by the manometer.

CHANGES IN THE HEART RATE IN THE INTACT ANIMAL.

The heart rate is very uniform during the first 50 to 60 per cent of the anoxemial test. Unless stimuli from the outside occur, this regularity is uninterrupted. Sooner or later, varying somewhat with the animal, the heart rate slowly and gradually augments. This increase continues along with the increase in blood pressure previously described. Whether the increase in rate is the chief factor producing the rising pressure has not been determined in this investigation, but Mathison speaks of vasomotor stimuli in the spinal animal. In an experiment running 15 minutes the increase in rate will be very apparent by the tenth or eleventh minute. It will progressively augment to a maximum at 13 or 14 minutes. The maximum rate is associated with or slightly precedes the maximum blood pressure. This group of responses of maximal heart rate, crest of blood pressure, and slowing and stopping of respirations is the complex for which we use the term "crisis."

After the rise of blood pressure passes its crest and while the respirations are beginning to slow and oxygen consumption is obviously decreasing, the heart rate also begins to slow. The decrease in heart rate is very gradual at first but rapidly becomes increasingly slower until the maximum rate is cut to a half or a third. In experiment 41 the slowing was from 161 to 44 beats per minute in 70 seconds.

If an animal with intact vagi is allowed to continue in the anoxemial state then the heart rate remains slow after the blood pressure falls, often stops for a few seconds at a time, and ultimately ceases altogether. The electrocardiographic record shows that beats continue many seconds after the manometer fails to record pressure changes. It takes an average of 3 or more minutes to run this cycle of changes after respirations cease.

CHANGES IN THE HEART RATE WHEN THE VAGI ARE CUT AT THE BEGINNING OF THE TEST.

If the vagus nerves are cut before beginning the experiment, the heart rate is of course at a higher level. However, for the first 50 or 60 per cent of the duration of the experiment there is no other change in the character of the rate.

During the last third of the experiment, passing through the crisis as indicated by the maximal blood pressure and stopping of respirations, the heart rate augments in the pre-crisis period and continues at a rapid rate during the post-crisis. There is no early cardiac slowing to the extremely low rate observed when the vagus nerves are intact. The rate remains uniform and high for from one and one-half to two minutes after respirations stop and until the blood pressure is falling rapidly. By the moment the blood pressure has declined to one-half its earlier maximal the heart rate has become very evenly and gradually slower. It beats more and more feebly until it stops or until irregularities develop. When the heart is beating too feebly to produce any visible movement of the meniscus of the manometer the electrocardiograms show it to be still contracting in a normal sequential rhythm. It keeps this up for many seconds but ultimately block or independent auricular or ventricular beats are established and death follows.

The early cardiac slowing observed in dogs with intact vagi does not occur in our animals with vagi cut. Neither is there any evidence of change in conductivity, or block in the early phase of the post-crisis period. These come only three to five minutes later and are only revealed by the electrocardiograms.

CHANGES IN THE HEART RATE AND BLOOD PRESSURE AS INFLUENCED BY CUTTING THE VAGI AT THE MAXIMUM SLOWING OF THE EARLY POST-CRISIS PERIOD OF THE INTACT ANIMAL.

The discussion of the preceding topics clearly indicates that there are two critical times as revealed by the changes in heart rate during the post-crisis period. The first is at the time of cardiac slowing in the normal intact animal at or near the moment when respirations stop. The second is the cardiac slowing that comes 3 to 5 minutes later in an animal in which the vagi are cut at the beginning of the experiment.

If at the moment of maximum slowing of this early period the vagi are cut, then the whole situation is rapidly altered. The facts are revealed by close comparison of typical experiments—i.e., Nos. 38, 40, and 41. In these experiments we secured complete respiratory, circulatory, and, in 40 and 41, electrocardiographic records without interruption through the entire post-crisis period. The vagi were cut in succession when the heart rates had dropped to between 40 and 50 per minute.

In experiment 38 the rise of blood pressure at the crisis was moderate but the heart slowing came on rapidly, the rate dropping from 176 at the crisis to 76 and then to 48 per minute. The right vagus was cut first, at 15 minutes from the beginning of the test and 45 seconds after respirations stopped. There was a sudden but momentary rise in blood pressure and an increase to a heart rate of 88, figure 23.

The left vagus was cut 40 seconds after the right. The heart rate immediately increased to 172, then 216. The original maximal rate was 174. The blood pressure at once rose to the maximal systolic pressure during the preceding period of slow heart beats, then as rapidly fell through 10 seconds, and more slowly through the next 40 seconds. Artificial respiration was then established, and the animal promptly recovered.

Cutting the right vagus led to an increase of rate from 48 to 88. The high pulse pressure, however, continued. Cutting the second or left vagus released the heart at once to its maximum rate at the crisis. One can not escape the deduction that the extreme post-crisis slowing was a vagus phenomenon—i.e., vagal spasm—from which the heart was immediately released when the vagus nerves were cut.

Experiment 41 was also used to test the effect of cutting the vagus nerve during the early slowing in the post-crisis period. The maximal blood pressure was high in this experiment, about 50 per cent above the pre-crisis average. The heart rate slowed during the interval of 45 seconds between the maximum blood pressure and the stopping of respirations. The manometer failed to record a few beats near the moment of stopping of respirations, but this does not veil the fact of the rapid and progressive cardiac slowing up to the moment when the right vagus was cut 35 seconds after respirations ceased.

For five heart beats preceding the cutting of the right vagus nerve the rate was at its lowest, 35 per minute. After one or two irregular beats at the moment of cutting the heart remained very regular and strong at the rate of 44 per minute. This was adequate to maintain the pressure at a uniform level during the interval.

The left vagus was then cut with a minimum amount of manipulation. The heart rate immediately rose from 44 to 180 per minute. The blood pressure was momentarily increased but followed by a fall at first rapid, then more slowly, until no further heart beats could be shown in the record of the manometer. The rate was well sustained until the pressure became low. Then the rate, too, slowly declined just as in experiments when the vagi were cut at the beginning.

A continuous electrocardiographic record was maintained until no heart beats were visible by this means. The details obtained by this method are given later. No effort was made to resuscitate this animal.

SUMMARY FROM THE BLOOD PRESSURE RECORDS.

The blood pressure records alone seem to prove that there are two post-crisis periods of slowing of the heart rate in anoxemia, the first a function of the vagus center, vagospasm, and the second a direct effect of oxygen-want on the heart itself. The electrocardiograms complete the evidence. We may therefore summarize the observations from blood-pressure records obtained by carrying anoxemia to the complete limit of stopping respirations and heart beats.

1. The reactions of the respiratory center of the medulla become at first slow, then cease. When lack of oxygen is pushed to the death there is a phase during which the respiratory center does not receive enough oxygen to maintain its normal discharges. Finally it ceases physiological activity from true anoxemia.

2. The inhibitory centers controlling heart rate do not fail as early as the respiratory mechanisms. This is indicated by the appearance of the maximal cardiac slowing after the respiratory center has ceased.

3. The cardiac slowing in the early post-crisis stage is not due to cardiac failure, i. e., muscle and bundle failure, since it does not occur if both vagus nerves are previously cut.

4. Direct cardiac anoxemia is not adequate to suppress heart activity until from three to five minutes after respiratory failure.

5. The extreme slowing occurring after respiratory failure is promptly removed only after cutting both vagi. It is immaterial which nerve is cut first in so far as the gross rates are concerned, though differences exist in the behavior of the heart controlled by the right or the left vagus only.

6. The extreme slowing is due to vagospasm which suppresses S-A rhythm. It is not ordinarily adequate to suppress A–V rhythm until anoxemia approaches a direct fatal effect. This slow rate therefore is an A–V rhythm released by vagus inhibition of S–A rhythm under the stress of anoxemia.

7. In extreme anoxemia when the vagi are intact inhibition may suppress the A–V rhythm. But when it occurs, a rhythmic center develops in the bundle branch, as in experiment 26, figured in Plate I, figures 4 and 5.

8. Considering the heart itself, it is proven that there is an interval of from three to five minutes following respiratory failure during which cardiac beats are maintained. The rate becomes progressively slower and slower. At any moment during this interval a supply of fresh oxygen by artificial respiration is adequate promptly to recover circulatory and respiratory efficiency and remove the vagal inhibition.

9. What we have proven true for the dog checks so closely with our observations on man in the early stages of post-crisis anoxemia that we can not but believe that the mechanism of the reaction is the same in man and the dog in the final stages of progressive loss of respiratory and circulatory function.

10. It follows that in man asphyxiation by anoxemia has a considerable margin of safety provided only that a few whiffs of oxygen can be introduced into the lungs within the three to five minute intervals during which the heart continues to beat following respiratory collapse. This interval is critical and success does not always follow artificial respirations in the chloretonized dog when no other aid to resuscitation is used.

EVIDENCE FROM THE ELECTROCARDIOGRAMS.

The electrocardiograms presented in the plates are all taken with the lead II. The lead was from the right shoulder to the left leg. Small nickel-plated electrodes were inserted through a slit under the skin and stitched into place for the early tests, but later nickel-plated binding posts were screwed directly into the head of the right humerus and into the shaft of the left femur. This last method proved very satisfactory and most convenient.

The normal dog electrocardiograms most often obtained are illustrated in either of the three normals in Plate II, Figure 8, Plate IV, Figure 25, and Plate V, Figure 35. The R is very tall and the T negative or at best diphasic, as in Figure 35.

As anoxemia proceeds the most typical change is in the T wave. It becomes positive, then increasingly taller until at times the T is as tall as the original R. (Figs. 30 and 41.) The maximum T is usually obtained at and following that stage of anoxemia in which respirations have just ceased. Figures 41 and 42 illustrate the change in the amplitude in the R, which decreases, and the S and T, which both augment during extreme anoxemia following sectioning of the vagi and preceding complete cardiac anoxemial asphyxiation. This cyclic increase of the T running through the post-crisis was obtained over and over again. It apparently does not depend upon change in the position of the heart. The early experiments were performed with the animal lying on its back. But later the animal was turned to a 45° angle toward its left side. In this position the filled ventricle would tend to fall toward the left at all stages of the test.

The changes in the duration of the different phases of the electrocardiograms in the main coincide with those already described for man (1). With acceleration up to the crisis there is a perceptible shortening of both P–R and R–T intervals.

POST-CRISIS CHANGES IN THE ELECTROCARDIOGRAMS WHEN THE VAGI ARE INTACT.

At the onset of the anoxemial crisis the blood pressure passes its crest and the heart rate becomes gradually slower. Plate II, Figures 9 and 10, Plate IV, Figure 27, and Plate V, Figure 38, all show this early slowing. This stage occurs at or preceding the moment of the stopping of respirations. Progressive slowing continues until the rate drops to one-half or one-third the normal. During the slowing the T wave greatly increases without other profound change.

Often the rate suddenly shifts, as in Plate V, Figure 39, to a lower level, during which profound change in the type of electrocardiogram occurs. In experiment 41 the change came at the sixth complex of Figure 39. The five preceding complexes show progressively longer P–R intervals, showing delayed conduction, at the sixth and two succeeding complexes S–A rhythm disappears and A–V rhythm becomes established. In the sixth complex the P wave is superimposed on the positive limb of the T. In the seventh it succeeds the T. In both cases the internodal conduction is reversed, i. e., proceeds from the A–V node toward the auricle. However, conduction is sharply delayed in the seventh complex.

The same phenomenon is shown in Figure 11, Plate II. The shift to A–V rhythm occurred in the second complex and those succeeding as described in the protocol of this experiment, No. 29. In Plate I, Figure 2, A–V rhythm was established in the third complex and continued with reversed conduction through a series of 29 beats, the last of which is shown in Figure 3 of this plate.

In Plate III, Figure 19, a type of anoxemial influence is shown, undoubtedly of vagus origin, namely, a primary influence on the conducting bundle. A 2–1 block appeared for four groups with a progressive decrease in the P–R interval, signifying a simultaneous displacement of the rhythmic center toward the tail of the S–A node. In short, the vagus here produced its strongest effect on conduction but it also inhibited rhythm to a degree. Later in the course of the anoxemia internodal conduction was occasionally blocked and rhythm of both auricles and ventricles was enormously slowed.

The type of vagus action which drives the rhythmic center toward the tail of the S–A node is best shown in Figure 28, Plate IV. This figure illustrates one of a series of groups of such variations in which there was a periodic return of the normal P–R interval. (See protocol, experiment 40.)

The most extreme type of inhibitory displacement of rhythm is illustrated in Figures 3 and 4 of Plate I. After 49 consecutive beats arising in the A–V node the rhythmic focus suddenly shifts to a center in the left bundle branch, the second complex in Figure 3. This type continued for 10 complexes at a rate of 26 per minute. Recovery occurred promptly on admitting air, the last complex in Figure 4. The last complex in Figure 13, Plate III, experiment 29, also shows a rhythm proceeding from a center in the left bundle branch. In neither of these two unique cases did conduction reach the auricle.

No reference has been found in the literature to any instance of a rhythmic center so low in the bundle system. But Dr. Frank N. Wilson has very kindly sent us a very clear electrocardiogram showing displacement of the pacemaker of this class which he obtained in the dog quite incidental to other experiments.[2] "The animals were given large doses of morphine, and this sometimes produced marked inhibition. In this particular animal a center located in the left bundle branch escaped and transitional complexes of the type mentioned by you occurred. In this instance I think no alternative explanation is possible." By Doctor Wilson's permission, this additional evidence is presented in Figure 43, Plate VI. Eyster and Meek's conception that the vagus suppresses cardiac function in the descending direction is carried a step further by these two experiments than has previously been suspected.

ELECTROCARDIOGRAMS WHEN THE VAGI ARE CUT.

If the vagi are both cut at the beginning of an anoxemial test, then no irregularities of the electrocardiographic complex occur in the early post-crisis period. It has already been explained that under these circumstances the rate is not slowed until late in the post-crisis asphyxiation, from 3 to 5 minutes or longer. Although the heart rate ultimately becomes gradually slower and finally stops, or becomes irregular, there is a long series of perfectly normal complexes, a series that extends through the slow and irregular rates of the early post-crisis shown in Figures 1, 7, 18, 23, 24, and 34, and in the electrocardiograms of the corresponding stages. Release from these early irregularities is best shown in Plates IV and V, illustrating the effects of cutting the vagus nerves in succession during the early crisis.

ELECTROCARDIOGRAPHIC CHANGES WHEN THE VAGI ARE CUT DURING THE EARLY CRISIS.

In Plate IV, Figures 29 and 30, the vagi were cut in succession at the moments indicated. When the first nerve was cut, in this case the left, there was little immediate effect on the rhythm, but the P wave was changed to a negative. A–V rhythm was permanently established and conduction was apparently reversed, but with occasional reversed block. Incidentally this illustrates the dominant influence of the right vagus on the rhythmic mechanism in contrast with the effect of cutting the left vagus first, as shown in Plate V, Figures 39, 40, and 41. When the right vagus was cut first, the immediate effect was a release to S–A rhythm. However, block was established at first in the 2–1 ratio and later complete, as shown by the independent S–A and A–V rhythms persisting until the second nerve was cut, Figures 39 to 41. These two experiments illustrate observations made by Cohn (13) showing the preponderance of influence of the right vagus on rhythm and the left vagus on conduction, except in our case the fact is brought out by anoxemial stimulation of the vagal center.

When the second nerve was cut in experiments of this type there was always an immediate escape to a rapid rhythm and a perfectly sequential beat that persists through several minutes, 3 to 8, before abnormality of the electrocardiographic complex was again displayed. Figures 30, Plate IV, and 41, Plate V, illustrate such escape.

Figures 6, Plate I, 31 of Plate IV, and 42 of Plate V, illustrate the effects of direct cardiac final anoxemial asphyxiation. These figures present terminal stages of the series of complexes after the vagi are both cut. They are always in the late or terminal post-crisis stage of anoxemia. The first two figures show a final block of conduction with persistence of S–A rhythm. Anoxemia here reduces the conductivity of the bundle system at a time when rhythmicity is still persistent in the upper node. The A–V node is also reduced in rhythmicity, though that property is not always completely suppressed. In both experiments, after a time, occasional independent ventricular complexes occur. These are illustrated in Figures 32 and 33.

The tracing in Figure 42 illustrates the terminal anoxemia in which rhythm was first suppressed. Whether conduction was still possible could not be determined since all rhythm was suppressed.

This series of electrocardiograms on anoxemial dogs confirms our suspicion that the slowing of rate and suppression of sino-auricular rhythm in man in the early post-crisis stage is a vagus effect. This stage is entirely removed in the dog when the vagi are sectioned. Freed from vagus influence, the heart is capable of sustaining an effective rhythm for some seconds and a physiological rhythm detectable by the electrocardiograph for at least three to eight minutes. The series clarifies the entire group of questions as to the relative danger in procedures which induce human anoxemial asphyxiation.

SUMMARY OF ELECTROCARDIOGRAPHIC CHANGES IN THE DOG DURING THE POST-CRISIS STAGES OF ANOXEMIA.

1. Electrocardiograms reveal the fact that the early post-crisis cardiac slowing is a strictly vagal influence on rate.
2. The degree of vagal anoxemial stimulation may completely inhibit the S–A rhythm or only drive the rhythm to a lower focus in the tail of the node.
3. When S–A rhythm is inhibited A–V rhythm becomes dominant but at a lower rate plane, 40 to 50. When A–V rhythm is established internodal conduction may still persist but in the reversed direction, producing an inverted sequence.
4. Extreme anoxemial inhibition drives the rhythmic center down into the bundle branch, in the demonstrations described in this paper the left bundle branch. Rhythm may persist here with fairly regular sequence through a demonstrated series of 10 beats. Rhythm may be entirely suppressed.
5. When the first vagus nerve is cut during anoxemial vagal stimulation the type of electrocardiogram changes, according to which nerve is cut first. If the right is cut first then the S–A rhythm often reappears but interference with conduction persists so as to produce inhibitory block. If the left is cut first then A–V rhythm persists with reversed conduction or reversed block.
6. When the second vagus is cut the heart always leaps forward to a rapid rhythm with even greater acceleration

[2] Private communication. Quoted by permission.

than during the precrisis stage. The electrocardiograms show that this rhythm is perfectly normal and sequential in type.

7. After a prolonged series of vagus free beats, through several minutes in experiment 40, through 400 consecutive beats in experiment 41, direct cardiac anoxemia occurs. Direct anoxemia slows the S-A rhythm as shown in all experiments, suppresses internodal conduction first as in experiments 36 and 40, or suppresses rhythm first as in experiment 41. At this stage of anoxemia the A-V center does not take on the rhythm but may occasionally discharge beats. The S-A center, however, is apparently last to become quiescent under direct cardiac oxygen want.

GENERAL DISCUSSION OF THE RESULTS.

Early papers by Sherrington (14), Roaf and Sherrington (15), Lewis and Mathison (16), and Mathison (4) present the initial literature describing heart block as a result of asphyxia in the mammal. These authors used decerebrate, atorpinized, and uninjured cats. A careful reading of their papers clearly pictures heart block as an interruption of auriculo-ventricular conduction associated with a great slowing in the heart rate. Lewis and Mathison describe prolongation of the P-R interval as introductory to simple heart block beginning with a 2-1 rhythm and leading up to complete block. They describe complete dissociation, also "a marked retardation of the auricular rate and this likewise is independent of inhibitory influences," with speedy and complete recovery. Clearly they exclude the phenomenon of inhibition. Mathison attributes heart block to "lack of oxygen rather than accumulation of carbon dioxide." He says "cardiac inhibition frequently comes on before heart block can appear," but obviously he does not associate heart block and inhibition as causal phenomena. He reports heart block in dogs when the vagi are cut.

We are unable to confirm heart block at the stage described by the above authors as a change initiated locally in the conducting tissues. Without exception our experiments on dogs have never shown the pronounced early slowing with heart block if the vagi are first cut. The initial heart block is present if the vagi are intact, absent if the vagi are cut in dogs. We agree with Mathison that the phenomenon is strictly due to a lack of oxygen. But the lack of oxygen leads to a stimulation, then suppression of respirations and to a profound increase in activity of the vagal center either overlapping or quickly following the stage at which respirations cease. If the vagi are not injured and anoxemia is allowed to take its course without artificial respiration, there is always a composite picture ultimately showing depression of conduction to the point of block; slowing of the auricle, as we think, by inhibition of the S-A node; establishment of independent ventricular or A-V rhythm due to inhibition of the S-A rhythm; and the occurrence of bundle branch beats, all from inhibition.

If the vagi are cut, then the normal high rhythm persists with sequential beats that result in sustained blood pressure for a minute or so after respirations cease. The fast rate continues straight through the early period during which anoxemial inhibition occurs when the vagi are intact.

After a more or less prolonged period, three to five minutes following the respiratory pause, and when the blood pressure approaches zero and the heart beats can no longer be readily distinguished by the mercury manometer, then a second and direct disturbance of the heart rhythm occurs. There is great slowing of the rate, heart block and independent rhythms. There is loss of auricular rhythm due to reversed block or of ventricular rhythm from direct block. Finally complete cardiac pause ensues. This seems to be the stage observed by Mathison and the onset by his methods was more abrupt than we observed.

A difficulty in correlating these facts with those related in the literature depends upon the fact that Mathison and the others used rapid methods to induce asphyxiation. The method of occlusion of the trachea suddenly withholds oxygen and fails to remove carbon dioxide, as does also the rebreathing of pure nitrogen from a bag. Our method of rebreathing purified air progressively withdraws oxygen. The rate of withdrawal used by us allows the body tissues and organs to progressively adapt to the condition of oxygen lack. There is less danger from misleading secondary reactions. On the whole a truer picture of uncomplicated anoxemia seems to result.

Mathison and others do not record normal respirations when they do occur and it is difficult to determine from blood pressures alone the corresponding times in the asphyxial cycle. Mathison's experiment 5 shows a long period of large variations in the blood pressure and a slower heart rate induced at about 60 seconds after beginning nitrogen respirations. The high blood pressure and large pulse amplitudes suggest that this phenomenon can not be the late and final direct anoxemia described by us. We are at a loss to explain the difference unless the cat and dog show a fundamental variation in this regard. We refer in comparison to our Figures 1, 18, 22, and 24.

Haggard (11) has recently studied carbon monoxide asphyxiation in which the blood changes and the electrocardiographic responses were observed in animals poisoned by carbon monoxide gas. He carried experiments to fatal terminations, also recovered animals after gassing. He atropinized animals but did not operate as a method of removing vagus influence.

Haggard did not take continuous electrocardiograms but his intermittent tracings show cardiac phenomena which at one time or another we have obtained, with the exception of ventricular fibrillation. His Figures 3 to 9 and 11 to 13 contain complexes that are common enough pictures in progressive anoxemia as obtained by our methods. One could interpret his results as due to true anoxemia rather than due to carbon monoxide an interpretation on which Gasser and Loevenhart based their method for inducing anoxemia. In our experiments also "the cardio-inhibitory center maintains its activity longer than does the respiratory center." Haggard (p. 398) describes a phenomenon which he attributes to "fatigued cardio-inhibitory center." We obtained some not very conclusive evidence on this point. In the preceding pages we have given the facts and explanations which will clarify Haggard's observation that after atropine and carbon monoxide "the heart maintains a rapid rate until the time of respiratory failure. Following this, the rate slowed, the P-R time increased and A-V block developed, but without the stage of auricular cessation noted in the unatropinized animals." The statement could be made of dogs under anoxemia provided we considered only the very early and the final effects of anoxemia, pictures due to two very different causes. It is apparent that Haggard missed the beautiful sequence, probably true for monoxide

asphyxia as well as for simple anoxemia, by not taking continuous electrocardiograms.

We deem it more than probable that the cycle of circulatory events is fundamentally similar by the various methods of producing anoxemia. The sequence and intensity of the reactions, however, must vary with the rapidity of the onset and with the rate and thoroughness with which oxygen is removed from the tissues. In the last and final extreme reduction of cellular oxygen suppresses the fires of physiological processes. However resistant the tissue or organ may be, its activity is smothered by oxygen want.

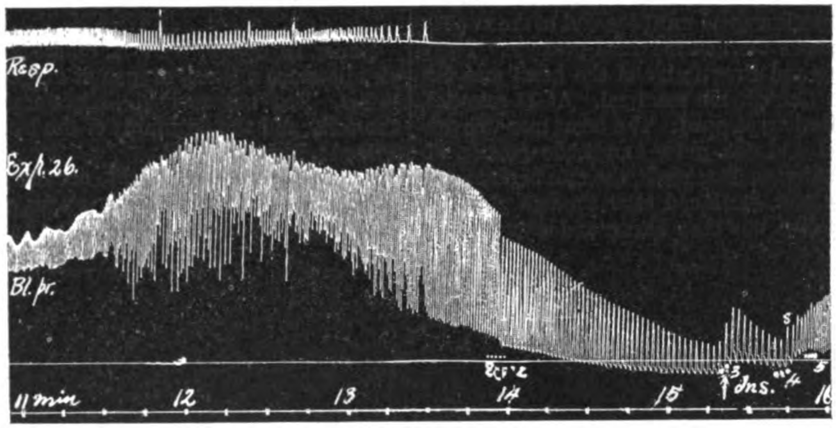


FIG. 1, EXPERIMENT 26.—The blood pressure and respiratory records show a somewhat unusual form of response to anoxemia. The blood pressure crisis exhibits two periods of maximal pressure with profound slowing of respiration at the onset of the first and stopping at the second. At 13 minutes 58 seconds the heart beat suddenly drops to a slower rate. Plate I, Figure 2, shows that this change is due to a shift from an S-A to an A-V rhythm. At 15 minutes 20 seconds insufflation was started. It had no influence on the electrocardiograms for 25 seconds when at 15 minutes 45 seconds regular sequential beats were reestablished on the particular beat marked S. (See also fig. 4.) The 10 beats following insufflation arise from a rhythmic point in the left bundle branch. Electrocardiograms are presented of the individual beats marked by dots. Magnification × 0.56.

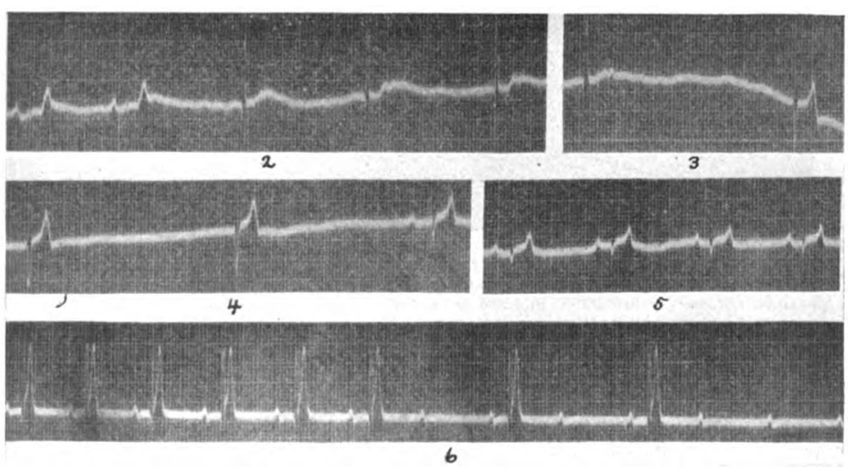


PLATE I. EXPERIMENT 26.—The positions of the electrocardiograms shown in Figures 2 to 5 of this plate are marked in the blood-pressure curve by dots under the corresponding beats. Figure 6 is the terminal record of experiment 36.

FIG. 2.—Five complexes recorded at 13 minutes 58 seconds, showing the shift in the rhythm from S-A to A-V origin. Extrinsic currents interfere but there is no very clear evidence of a P wave. Possibly the slight negative depressions in the T-waves of the last two complexes can be attributed to the auricle. There are 49 complexes in this group. Definite and clear reversed conduction characterizes the last 29.

FIG. 3.—At this point A-V rhythm with reversed conduction suddenly ceased and a ventricular complex characteristic of left ventricular dominance and bundle-branch origin began. This type runs for 10 successive contractions. These contractions are explained on the assumption of origin of the beat in the base of the left bundle branch.

FIG. 4.—The two complexes of left bundle-branch origin are followed by one sequential beat. Sequential contractions continued until complete recovery of normal rate and conduction. The sequential beats have at first a relatively long P-R interval, but conduction slowly improved under insufflation.

FIG. 5.—Fifth to eighth sequential beats during the recovery under insufflation.

FIG. 6.—This excerpt from a continuous electrocardiographic record of experiment 36 through seven minutes after respirations stopped shows the direct asphyxial effect on the heart when the vagi are cut. The rate progressively slowed to the auricular rate shown in this figure, 14 minutes. Then there occurred 2-1 block for two periods followed by complete block. During the last minute and a half of the entire record six independent ventricular complexes occurred. When the electrocardiographic record ceased the auricular rate was still 25 per minute and regular.

PROTOCOL.

Experiment 26, dog 12, wt. 10 K. Chloretone 0.3 gram per K., air allowance 3 liters, oxygen at the crises 4.5 per cent. Electrocardiograms.

This experiment ran through a very even and uniform precrisis period showing a gradual use of oxygen and little or no variations of blood pressure until the eleventh minute. Blood pressure then increased until the end of the twelfth minute, which marks the first maximal pressure. There was great slowing and irregularity of the heart rate but normal sequence through the maximal. At 13 minutes, 30 seconds, respirations stopped. The heart rate was progressively slowed and the pulse amplitude greatly increased. At 13 minutes, 58 seconds, the rate became suddenly very slow and continued slow through about 80 seconds. Insufflation was then begun and after 10 very introduced enough oxygen to bring about a normal sequential heart beat of increasing rate and final recovery.

This whole phenomenon is interpreted as vagal stimulation by anoxemia at the center. The most striking new observation is the fact that anoxemia affects the vagal center profoundly enough to drive the rhythm to a point so low as the left bundle branch.

PROTOCOL.

Exper. 29, dog 13, Wt. 9 K. Chloretone 0.3 gram per K., air allowance 4 liters, oxygen at end 2.2 per cent. Vagi intact. Dog not revived. Electrocardiograms through the early and the beginning of the late anoxemial state, Plate II, Figures 8 to 16.

Anesthesia relatively light, occasional skeletal muscle contractions during the early stages of the experiment. Respirations rapid at the beginning but very slow and irregular from the fourth to the eighth minute and regular and typical during the last portion of the test.

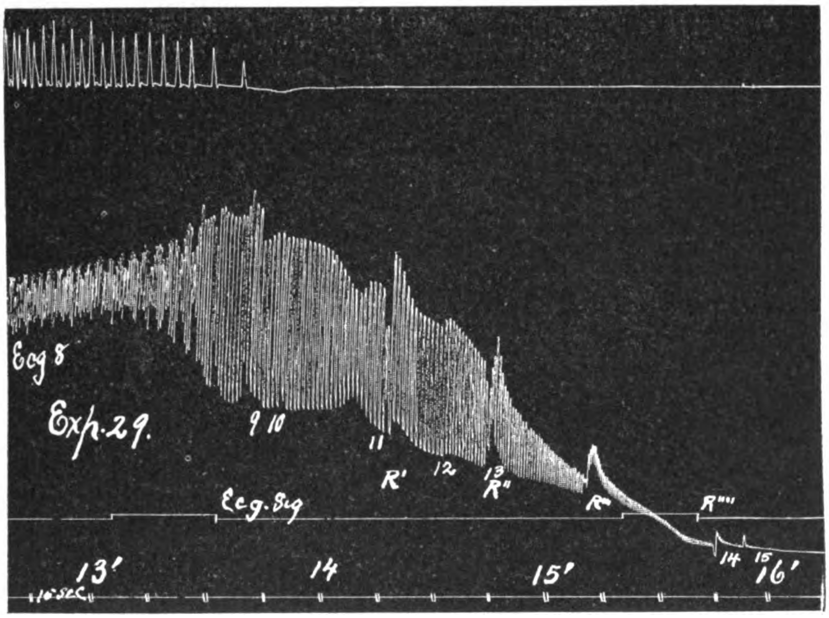


FIG. 7.—EXPERIMENT 29.—The respiratory and blood-pressure tracings at the terminus of the test. Top line respiratory movements which ceased at 13 minutes 44 seconds. Middle line blood pressure. The maximum or crisis occurred at 13 minutes 30 seconds. The numbers below the blood-pressure tracing indicate points figured in the electrocardiograms, Plate II, Figures 10 to 17, inclusive. *R'*, *R''*, *R'''*. *R''''* respiratory gasps occurred after rhythmic respirations had ceased. No attempt at recovery. Magnification × 0.68.

slow beats recovery occurred rapidly, at 15 minutes, 45 seconds. This point is marked in Figure 1 by the letter S over the first normal or sequential contraction in the recovery.

Continuous electrocardiograms beginning at 12 minutes were obtained. (See Plate I, figs. 2 to 5.) The electrocardiograms showed slow and irregular rhythm but no abnormal sequences until 13 minutes, 58 seconds, when the rhythm shifted from an S–A to an A–V origin, Figure 2. With the shift the Q wave appeared and was followed by an exceptionally tall R wave, 16 mm., in comparison with the normal sequential complex which in this animal showed an R of only 2 to 3 mm. At 15 minutes, 22 seconds, the origin of the rhythm shifted to a still lower point in the A–V bundle system, Figure 3. The complex from the new focus has an S wave of 10 mm. amplitude and a tall positive T wave. It is typical of left ventricular dominance but its type shows bundle origin. The focal center is apparently in the left bundle branch and remains here for the next 10 beats. After 10 beats insufflation

Blood pressure was more sensitive to external or reflex stimulation than usual. There were two maximal pressure waves separated by 1.5 minutes, Figure 7. From 13 minutes, the heart progressively slowed until at the last respiration the pulse amplitude was 70 mm. From the moment of the last respiration blood pressure fell uniformly through 2.5 minutes, when the heartbeats were no longer strong enough to record. The heart rate remained uniformly slow through seventy-odd seconds, then gradually increased in rate but still decreased in amplitude. At 16 minutes, the pulse cannot be counted on the blood-pressure tracing, though it is clear and sequential in the electrocardiograms.

There were four respiratory gasps after regular respirations stopped. The second and third are followed by a slight increase in heart rate.

The electrocardiograms showed the usual normal—P 2 mm., Q slight, R 21 mm., S none, T negative 4.5 mm., P–R 0.098 seconds, R–T 0.200 seconds, rate 140 per minute.

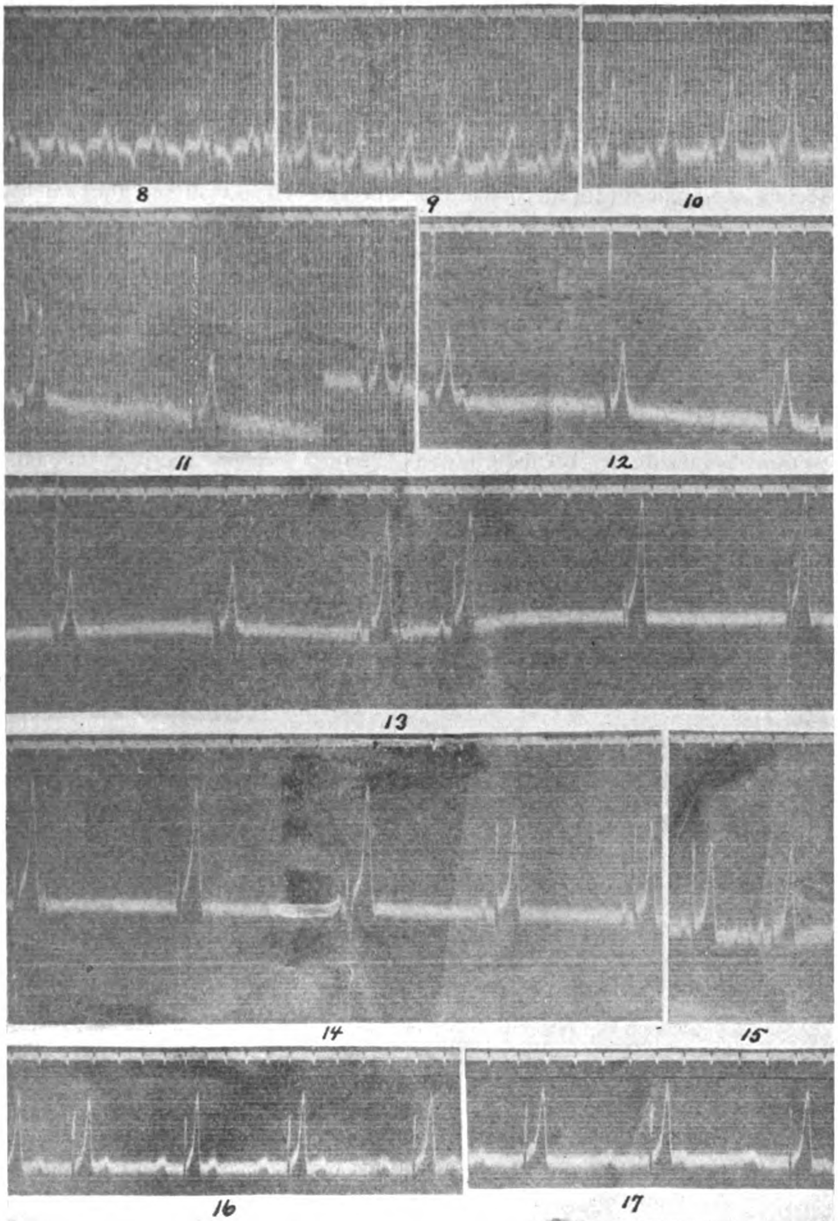


Plate II, Experiment 29.—Fig. 8.—Normal electrocardiograms. Note the characteristic tall R and the negative T waves.

Fig. 9.—Time, 12 minutes 23 seconds. The T wave had changed from a negative to a positive 16 seconds earlier. R now decreasing.

Fig. 10.—Time, 12 minutes 53 seconds. Both the R and the T waves progressively increased between Figures 9 and 10.

Fig. 11.—Time, 13 minutes 42 seconds. Rapid inhibitory slowing of the rate (vagal) during the preceding 10 beats. S-A rhythm inhibited and A-V established at this point. Reversed conduction continued through 9 beats with block on the second, third, and ninth between this and Figure 12.

Fig. 12.—Time, 13 minutes 56 seconds. Reversed conduction blocked in the second complex and permanently blocked in a series of complexes following this point. Note the delay of reversed conduction in the third complex compared with the first in this figure.

Fig. 13.—Time, 14 minutes 15 seconds. Transitions occur in the pacemaker along the A-V node ending in a ventricular beat with left dominance in the last complex. The third and fourth complexes occur at the first anoxemial respiratory gasp, shown in the blood-pressure curve, Figure 7, and are due to momentary but partial suppression of the vagal inhibition.

Fig. 14.—Time, 14 minutes 30 seconds. Sudden transition from deep A-V rhythm to a normal sequential but slow rhythm. From this point no further irregularities in sequence occur until permanent block appeared 80 seconds later.

Fig. 15.—Time 14 minutes 45 seconds. Momentary auricular flutter at the second respiratory gasp shown in Figure 13. Sequence normal when it occurs.

Fig. 16.—Time, 15 minutes 50 seconds. Appearance of direct anoxemial block to 2-1 rhythm. For the preceding 30 seconds the P-R became progressively longer, from 0.12 second to 0.28 second. The duration of the auricular contraction also progressively increased as shown in this figure.

Fig. 17.—Time, 16 minutes. Establishment of permanent block but with both S-A and A-V rhythms still occurring. The record not taken beyond this point.

At 12 minutes, 7 seconds, the T wave became positive. At 12 minutes, 23 seconds, Figure 2, the T wave had increased to 6.5 mm. At 12 minutes, 53 seconds, the T had reached an amplitude of 12 to 14 mm. At about 13 minutes, 30 seconds, the slowing is more pronounced, and at 13 minutes, 42 seconds, S–A ryhthm was inhibited and A–V rhythm established, Figure 11, Plate II. The type of reversed conduction shown in the third complex of Figure 11 continues through 9 beats, after which for 23 consecutive beats there was no evidence of auricular action. The twenty-fourth and twenty-fifth beats, the third and fourth of Figure 13, are sequential. At this point the first respiratory gasp shown in Figure 7 occurred. These are followed by 10 beats with no P wave in evidence.

On the last complex of Figure 13, the character of the complex changes. There is now a very short R wave, deep and profound S, and a continued tall T. This is a typical left ventricular dominance. This we also explain by assuming that at this point the origin of the rhythm shifted down the A–V node to a still lower point in the conducting system, to the left bundle branch. This type of beat gradually shifted back to the normal sequential beat as shown in Figure 14. The first complex in Figure 14 introduced reversed conduction. In the third complex the P wave occurred before the ventricular complex, and in the fourth and fifth the regular sequential beats appeared and continued for some 12 beats before a second respiratory disturbance occurred. The third complex in Figure 14 shows left ventricular dominance but an auricular beat occurs higher up either in the tail of the S–A node or in the atrial groove. Possibly the left ventricular type in this case can be attributed to relative right bundle block rather than left bundle rhythm. If so, it would indicate an influence of the vagus nerve on conduction extending well down into the ventricular portion of the bundle system and greater on the right bundle.

Sequential beats continued from 14 minutes 30 seconds through to 15 minutes 50 seconds, when partial 2–1 block occurred as shown in Figure 16. In the meantime the duration of the P wave and the length of the P–R interval very progressively increased to the extreme degree shown in Figure 16, when 2–1 block was established. The electrocardiographic record ceased at 16 minutes with the type of record shown in Figure 17, 2 minutes 20 seconds after respirations ceased.

The reestablishment of sequential beats after the extreme inhibition shown in the first anoxemial slowing indicates a partial escape from the vagal inhibition of conduction. Henderson and Haggard have given evidence indicating a similar phenomenon of escape after carbon monoxide asphyxiation.

PROTOCOL.

Exper. 33, dog 16, wt. 7.5 K. Chloretone 0.3 gram per K., air allowance 4 liters, oxygen reached 4.37 per cent. Vagi intact. Electrocardiograms throughout the critical asphyxial stage, Plate III, Figures 19 to 21.

An excellent record of respirations and blood pressure was obtained with unusual features in the terminal phase. Electrocardiograms continue through the entire critical post-crisis period, Figure 18, and Plate III, Figures 19, 20, and 21. The respiratory record shows a very uniform consumption of oxygen to 10 minutes, a progressive falling off of oxygen used until respiration ceased at 12 minutes 20 seconds.

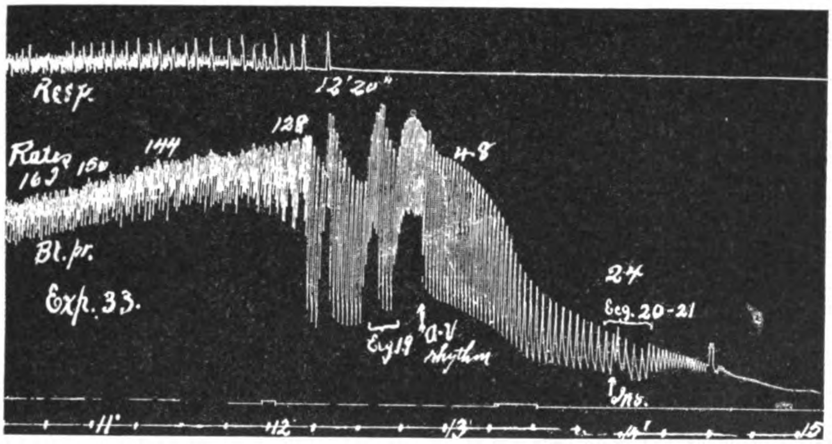


FIG. 18, EXPERIMENT 33.—The terminal stage of experiment 33, vagi intact. The numbers above the blood-pressure curve are heart rates per minute. At the blood-pressure crisis three great irregularities in the heart rate appear, i.e., three groups of slow rates each followed by a momentary recovery. These periods are in reality 2-1 blocks as shown by the electrocardiograms, Plate III, Figure 19. *Ecg. 1* and *ecg. 2-3* are figured in Plate III. *A-V rhythm* marks the point where the S-A rhythm was completely inhibited. *Ins.*, insufflation began. On the fifth beat, the last complex of Figure 21 of the electrocardiographic series, normal S-A rhythm was reestablished. Magnification × 0.59.

The rise of blood pressure was sharp during the crisis, notwithstanding the fact that the heart rate slowly decreased from 160 at 10 minutes 40 seconds to 128 at the time of maximum pressure, 12 minutes. There are four periods of pronounced cardiac slowing during the thirteenth minute, the first occurring between the last two respirations, Figure 18.

At the beginning of the 4th pronounced period of slowing marked *A V rhythm* on the figure, auricular contractions disappeared, leaving a pure ventricular complex. Occasionally there was reversed conduction with a rather long R–P interval, Figures 20 and 21. Beginning with the last complex in Figure 21, sequential rhythm was established, and the rate increased as shown in the blood-pressure tracing, Figure 18. This was possibly a release from the vagus anoxemial inhibition on account of the entrance of air obtained through insufflation begun at 13 minutes 55 seconds. However, no recovery of the animal occurred.

PROTOCOL.

Exper. 36, dog 18, wt. 10 K., chloretone and ether, air allowance 4.5 liters, oxygen at the end 3.46 per cent. Vagi cut at the beginning. Dog not revived. Continuous electrocardiograms for 6 minutes, beginning 10 seconds before respirations ceased, Plate I, Figure 6.

Respirations very irregular, rather rapid until the last minute when they slowed down at the anoxemial crisis.

The blood pressure increased at the moment both vagi were cut at the beginning of the experiment and remained high until anoxemia appeared. The pressure then very gradually decreased with failing respiration. No slow beats at the crisis, very regular heart rate with gradual decrease in pulse amplitude until the variations were no longer recorded by the manometer, Figure 22. Sequential complexes figured are 0.200 second, 0.200, 0.200, 0.208, 0.212, 0.220, 0.232, block, 0.228, block now complete. Six irregular and independent ventricular complexes occurred late after the development of block.

PROTOCOL.

Exper. 38, dog 19, wt. 9 K., chloretone 0.3 gram per K., air allowance 4 liters, oxygen at crisis 2.38 per cent. No electrocardiograms. Respiratory and blood-pressure curves.

Respirations rapid, use of oxygen uniform, but decreasing at the very last before respirations ceased at 14 minutes 16 seconds.

The rise of blood pressure was moderate at the crisis. Heart rate at its maximum at 13 minutes 30 seconds, near the crest of maximal blood pressure. The heart slowing began about 30 seconds before the respirations ceased, became very profound at 14 minutes 35 seconds, with a rate of 44 per minute. The right vagus was cut at 14 minutes 58 seconds. The rate immediately doubled in partial release. The left vagus was cut at 15 minutes 40 seconds. At this point the rate was released to 216 per minute, a greater rate than at the maximal blood pressure. During the interval between the cutting of the right and left vagus nerves the blood pressure was relatively high and the pulse amplitude great. (See Fig. 23.)

Artificial respirations were established before anoxemia had advanced to the second asphyxial stage, natural respirations returned at 17 minutes 15 seconds.

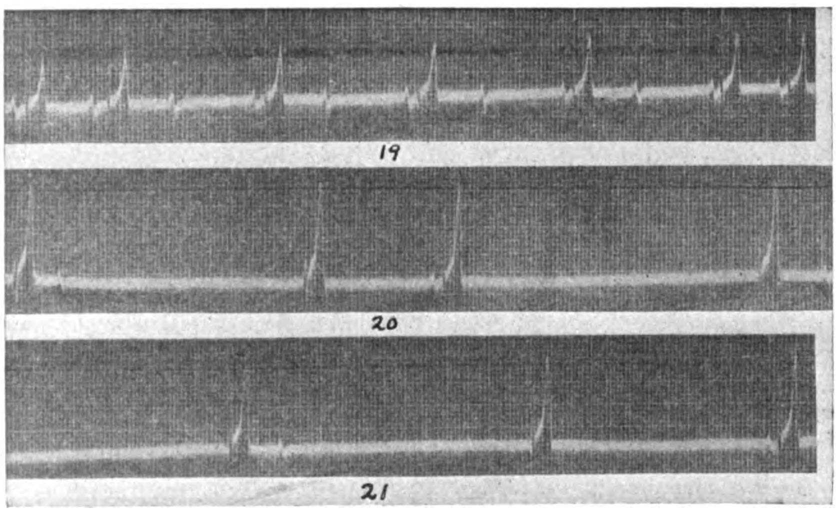


PLATE III, EXPERIMENT 33.—FIG. 19.—This figures the third group of four beats at a slow rate as shown in the blood-pressure curve of experiment 33. Four auricular contractions are shown to be blocked and a 2-1 rhythm occurs. Recovery of conduction extended through the succeeding rapid period shown in the blood-pressure curve.

FIG. 20.—An A-V rhythm has persisted through the preceding 70 seconds. Reversed conduction occurs occasionally only. It is shown in the first and fourth complexes of this figure. Reversed block occurs in the second complex. The third complex is produced by an escape to S-A rhythm at the moment when insufflation began, see the blood-pressure curve, Figure 18.

FIG. 21.—Continuation of Figure 20, showing reversed conduction, block, and the permanent return of S-A control beginning with the fast complex. From this point on sequence is normal and the rate progressively increases.

heart beats to 14 minutes 30 seconds, Plate I, Figure 6. At 4 minutes 5 seconds after respirations stopped, complete block occurred. The auricle continued to beat with regular but decreasing rhythm for 7 minutes 35 seconds after respirations ceased. The auricular rate was 25 per minute at this time when the electrocardio-graphic record was stopped. The development of heart block in this experiment was like that in experiment 40, Plate IV, Figure 32.

In this experiment conduction was first eliminated in the late anoxemial asphyxiation of the tissue as in experiment 40. The electrocardiograms show that the inception of block was preceded by a group of rapidly lengthening P–R intervals. The P–R intervals in the

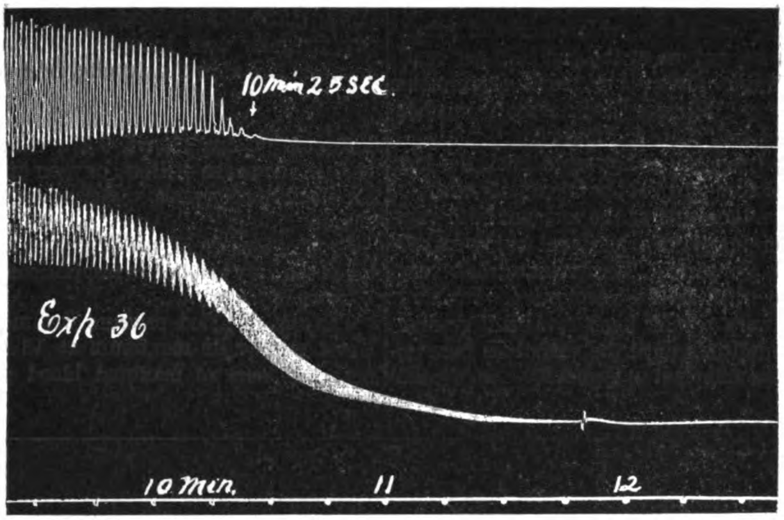


FIG. 22, EXPERIMENT 36.—Showing the terminal respiratory and blood-pressure records of a comparatively infrequent type of response to anoxemia when the vagi are cut at the beginning of the test. Respirations ceased at 10 minutes 25 seconds while the dog was inspiring 3.62 per cent oxygen and 0.45 per cent carbon dioxide. The blood pressure declined earlier than the rule, but the heart rate was sustained in normal sequence for 3.5 minutes and the auricles still contracted at the end of 17.5 minutes when the record was discontinued. Figure 6, Plate I, shows the beginning of direct asphyxial heart block at 14 minutes. Magnification × 0.76.

PROTOCOL.

Exper. 40, dog 20, wt. 16 K., chloretone 0.3 gram per K., air allowance 4 liters, oxygen at end 2.5 per cent. Electrocardiograms. Vagi cut during the cardiac slowing following the respiratory crisis. Insufflation but no recovery.

The blood pressure was very uniform and even until the sixth minute when the pressure began to rise and the heart rate to increase. The maximum pressure was reached at the moment when respirations stopped, although the average high pressure was maintained one minute and more longer.

Between the last two respirations 22 heart beats occurred. Following the last respiration there are 56 beats to the point marked *left vaguscut*, Figure 24. These groups are each slower than the preceding. At the last group of 12 beats the blood pressure was 158 and the pulse amplitude 80. When the left vagus was cut slow swinging pulses occurred to the point marked *R. V. cut.* There are four slight irregularities in this series; otherwise they are remarkably even, though the pulse amplitudes progressively decreased. Counting the four irregularities, there are 62 beats in the interval. When the right vagus

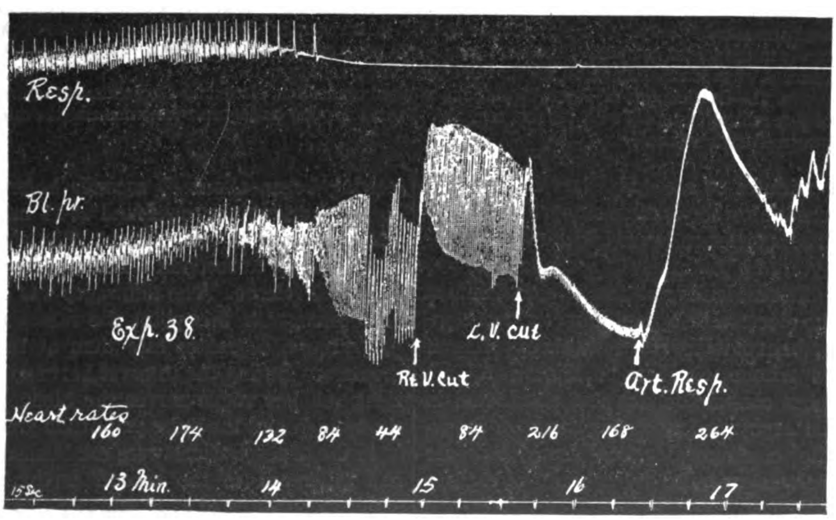


FIG. 23, EXPERIMENT 38.—Slowing of the heart rate began at 13 minutes 40 seconds, and at 14 minutes 30 seconds had dropped to 44. The right vagus was cut at the point marked. There was an immediate increase of the rate to 88 per minute. When the left vagus was cut the rate immediately escaped to the precrisis figure and rapidly ran up to 216 per minute. No electrocardiograms were obtained. The heart rates are given on the tracing. Magnification × 0.54.

was cut the pressure was 122 with pulse amplitudes of 68. Instantly the heart rate increased and the pressure struck a maximum of 130, rapidly falling to 108 in 8 or 10 seconds. After a small group of very irregular pressures a very regular series of heart beats and even pressure variations occurred through 25 seconds, the pressure at the beginning averaging 86. At the end of this regular group the pressure was 76. Insufflation then produced irregularities in the blood pressure, which, however, continued to fall. No recovery was obtained.

The normal electrocardiogram did not vary from the usual type. The R was tall, 23 mm., and T diphasic with the negative wave moderate. This type continued through the records of the fourth and eighth minutes. Continuous electrocardiograms began at 8 minutes 55 seconds, and ran through the entire post crisis. At the beginning of the continuous record the T wave was positive, 9 mm. in amplitude. By counting the regular beats corresponding to the first, second, and third blood-pressure groups preceding the cutting of the left vagus, it was easy to identify the of the nerve have buried P waves, so also the first beat following the cut. The third complex shows a well-marked reversed conduction, the P wave occurring late in the T. This auricular complex began a series of negative P waves running through the entire group of electrocardiograms until the second or right vagus was cut. The fifth beat showed a reversed conduction time of 0.216 second, in the sixth beat the R–P interval is 0.328 second, if indeed this P should not be considered as belonging to the following complex. The next five or six contractions introduce variations of similar type, and this phenomenon recurred at intervals until the second vagus was cut. Certain ventricular complexes show no associated auricular contractions.

At the intervals between the fifty-eighth and sixty-third beats after cutting the left vagus, there are variations in the iso-electric period which mark the lifting and cutting of the right vagus nerve. Although the nerve was cut promptly the exact point of cutting is in doubt. The sixty-fourth beat is partially recorded only. The sixty-fifth beat and the series that follow are normal sequential complexes increasing very rapidly in rate and decreasing in the amplitude of the T, through eighteen or twenty beats. The eighteenth recovery beat is at a rate of 242, P–R 0.104 second, R–T 0.104 second, P 1.6 with rather broad base, Q 1, R 17, S none, and T 7. After the twenty-second beat there was some irregularity in the sequence.

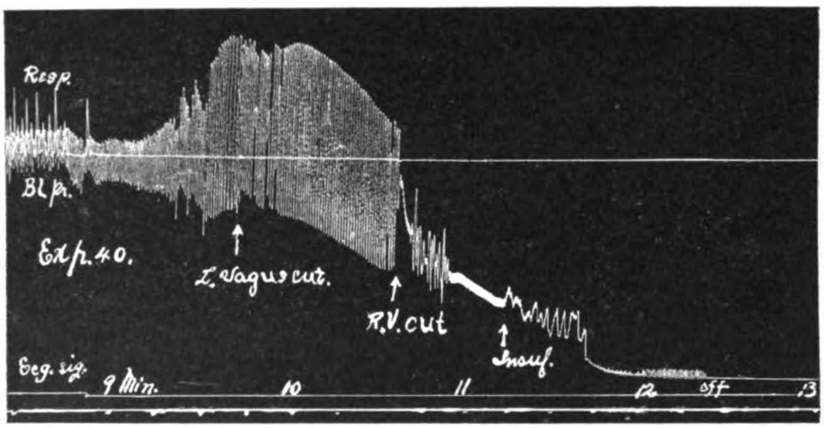


FIG. 24, EXPERIMENT 40.—Respirations stop at 8 minutes 56 seconds. Fifty seconds later the left vagus was cut. At 10 minutes 35 seconds the right vagus was cut. *Insuf.*, insufflation began but changed to bellows and stopped at *off*. No recovery. The electrocardiographic record was continuous from 8 minutes 54 seconds to 17 minutes 40 seconds. At 12 minutes 50 seconds independent auricular and ventricular rhythms, i.e., complete block, was established. At 14 minutes 40 seconds the auricular electrocardiograms were still regular but became too weak to photograph. At 17 minutes 40 seconds the ventricle was contracting irregularly at about 6 per minute. The record was then stopped at 7 minutes 46 seconds after natural respirations ceased. The time line is raised to 30 mm. pressure. Magnification × 0.59.

irregularities in the electrocardiograms. They are associated with a series of progressive shortenings of the P–R intervals. Measuring straight through the three irregular periods shown in the blood-pressure record before the left vagus was cut we have the following P–R times in order: First beat, 0.112 second; second, 0.100; third, 0.092; fourth, 0.080; fifth, 0.084; sixth, 0.064; seventh, 0.072; eighth, 0.052; ninth, 0.012; tenth, 000; eleventh, 0.128; twelfth, 0.100; thirteenth, 0.112; fourteenth, 0.108; fifteenth, 0.092; sixteenth, 0.052; seventeenth, 000; eighteenth, 0.136; nineteenth, 0.116; twentieth, 0.100; twenty-first, 0.088; twenty-second, 0.056; twenty-third, 0.020; twenty-fourth, −0.040 (reversed conduction); twenty-fifth, 0.112; twenty-sixth, 0.092; twenty-seventh, 0.088; twenty-eighth, 0.084; twenty-ninth, 0.120. These conduction times identify the irregularities as due to a progressive displacement of the rhythmic center in the descending direction the most striking in our series. The tenth, seventeenth, and twenty-fourth are the critical complexes, Plate IV, Figure 28.

At the point marked, "Plate IV, Figure 29," the first or left vagus was cut. The two beats preceding the section

For about 40 seconds following the section of the second vagus the record was regular and uniform with slight broad wavelike variations (suggestive of some extrinsic influence). At the stage of anoxemia when these end the T waves greatly augment, changing from 6 to 10 mm. in about ten beats. The P–R interval lengthens to 0.14 second. At the end of the tracing the T wave had increased to 16 mm. and the P–R to 0.16 second and the rate had slowed to 106 per minute. These complexes are regular and slow sequential beats with tall T waves and increasingly long P–R intervals. The ten complexes preceding complete and final block have P–R intervals that measure 0.136 second, 0.152, 0.152, 0.160, 0.160, 0.168, 0.220, 0.232, block, and 0.248. All succeeding contractions are blocked, Figure

31. A regular auricular rhythm continued through about 2 minutes but the P waves became increasingly faint until they could not be distinguished at 14 minutes 50 seconds.

Occasional ventricular complexes occur during this time. The first one is fused with an auricular complex, the second, third, and fourth are obviously independent, and fifth appears so but follows a P wave by 0.092 second, the sixth and seventh follow P waves by 0.180 second, the eighth by 0.008 second, and in the ninth P is buried in the ventricular complex. The ventricular rhythm is obviously wholly independent.

The auricular rate dropped from 100 to about 26 per minute during the time of block. Ventricular complexes only are visible throughout the electrocardiographic records of the fifth and sixth minutes after respirations ceased. These are at a low but fairly regular rate, about 12 per minute at first but 6 per minute in the tracing which closes our record, Figure 33.

The disturbances following the stopping of respiration can in this case all be attributed to vagospasm. They disappear on cutting both vagus nerves. The sequential rhythm that returns is perfectly comparable to that of experiments in which the vagus nerves were cut before anoxemial asphyxiation began. In this experiment when the heart itself became asphyxiated sequential beats were suddenly stopped by block. The auricle continued in regular rhythm through many seconds until finally the auricular complex became too faint to be distinguished. In the meantime independent ventricular complexes at long but comparatively regular intervals appeared and persisted to the end of our record. The appearance of augmented T waves with the onset of the period of slowing

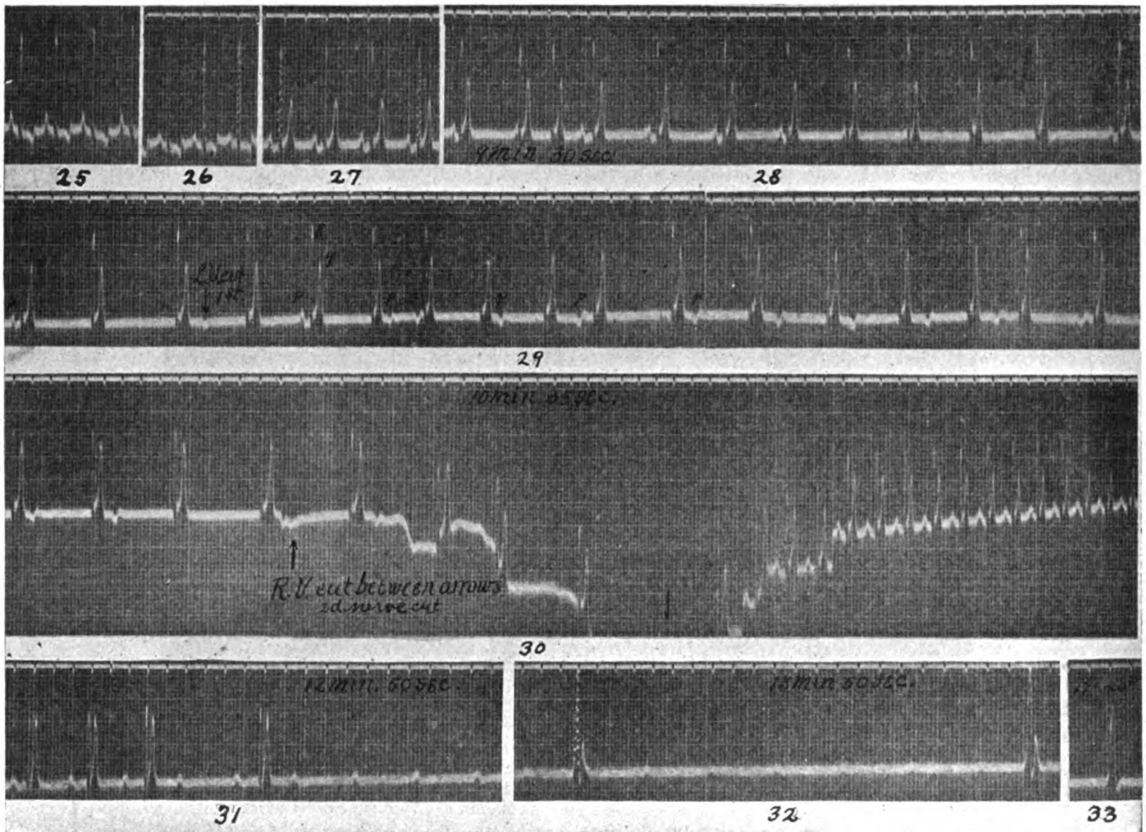


PLATE IV, EXPERIMENT 40.—FIG. 25.—Normal electrocardiograms, showing negative T waves.

FIG. 26.—Seven minutes 30 seconds from the beginning of the anoxemial test.

FIG. 27.—Eight minutes 55 seconds from the beginning of anoxemia. End of respirations. T wave became positive at 8 minutes.

FIG. 28.—Nine minutes 30 seconds. Periodic inhibitory displacement of the rhythmic center in the descending direction, each period ending in apparent block but probably buried P waves.

FIG. 29.—The left vagus was cut at the mark *L. V. cut*, 9 minutes 50 seconds. In the third complex the P is inverted and conduction is retrogressive. From this point through the interval before the cutting of the second vagus the P wave was always inverted. conduction was reversed and occasionally there was reversed block.

FIG. 30.—At 10 minutes 35 seconds the second or right vagus was cut somewhere between the points marked, probably at the second arrow. After a few beats normal sequential rhythm was rapidly reestablished, the rate increasing through the first 10 or 15 contractions following the second arrow.

FIG. 31.—At 12 minutes 50 seconds, or 2 minutes 15 seconds after both vagi were sectioned, complete anoxemial block appeared. The auricle continued to beat in regular rhythm from the S-A center but the ventricle ceased beating. After a long interval occasional independent ventricular complexes appeared with increasing frequency.

FIG. 32.—Thirteen minutes 50 seconds. The ventricle now contracted at the rate of 14 to 15 per minute. The auricular rate was about 90. One minute later the auricular complexes were too weak to record.

FIG. 33.—The last recorded ventricular complex, 17 minutes 40 seconds after respirations ceased.

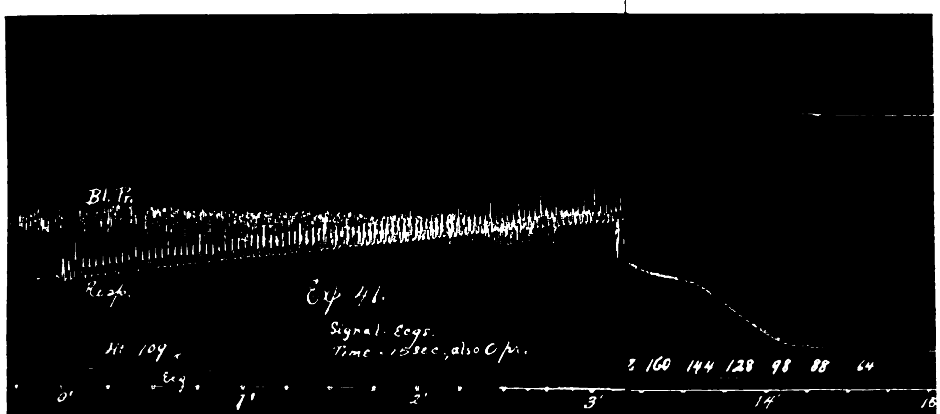
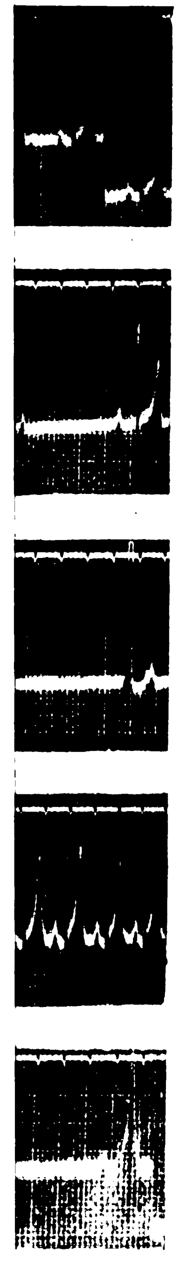


FIG. 34, EXPERIMENT 41.—Blood pressure and respirations through the en rations of any kind. Note the uniform rate of oxygen consumption until the anoxemial crisis approached. The origin

5165—22 (Face p. 53.) No. 1



les with the T but
g at the beginning

le as do the succes-

e second, the heart

last, the R waves
ct asphyxiation.

of the heart from cardiac tissue anoxemia was typical of the course of other experiments.

Insufflation used late in the test when blood pressure was low but while normal electrocardiograms were running was unsuccessful toward reviving the animal, in fact had no observable effects.

PROTOCOL.

Exper. 41, dog 19, wt. 19 K., chloretone 0.3 gram per K., air allowance 4 liters, oxygen reduced to 1.8 per cent, electrocardiograms, blood pressure, vagi cut at the crisis.

Respirations comparatively regular for 6 minutes, then rapid and irregular to 7 minutes, increasing rate and amplitude to 9 minutes, decreasing amplitude 9 to 11 minutes, decreasing rate 10 to 11 minutes. Respirations cease at 11 minutes. For the first 6 minutes deeper individual inspirations occur about every sixth respiration, from 6 to 8 minutes fewer deep inspirations, from 8 to 10 minutes more frequent deep gasps that become very marked near the end at 11 minutes.

The blood pressure was very uniform and even, one of the most regular records of the series. After 5 minutes it slowly and progressively increased to a maximum at 10 minutes 25 seconds. The maximum pressure came about 40 seconds before respirations stopped but after a decrease in the use of oxygen was apparent. The blood pressure fell very slightly through 40 seconds, then somewhat more rapidly until the vagus nerves were cut. (See fig. 24.) Later the pressure fell promptly to the level shown in the figure. The events are figured through only 4 minutes after respirations stopped.

The heart rate began at 109 per minute. In the fifth minute it had increased to 118, 121 in the eighth, 156 in the tenth, and 161 at 10 minutes 15 seconds. The rate rapidly fell then to 145 and finally 44 when the right vagus was cut. There were no changes in heart rate between the cutting of the right and left vagi. When the second or left vagus was cut the rate immediately increased to a maximum of 185, then decreased through the rates shown in the figure to 64 at 14 minutes 40 seconds, after which the manometer no longer recorded, though the electrocardiograph recorded complexes for 30 seconds more, when the heart stopped completely as shown in Plate V, Figure 42.

When the second vagus was cut the blood pressure immediately increased, then dropped again in 5 seconds, Figure 34. This was followed by a slight second rise in pressure, then a progressive decline through 2 minutes 25 seconds, when the heart beats were no longer visible on the manometric record. The heart rates through this period were as follows: 15 seconds before the vagus was cut 11 beats, and by 15-second periods after cutting, 44, 40, 40, 40, 36, 30, 24, and 20 on the ninth period, but for the tenth not visible.

The continuous electrocardiographic tracing, beginning at 8 minutes 45 seconds, shows beside the cardiac complexes certain gross waves corresponding to the respiratory rhythm. Periodically these waves are larger and check with the recorded deep sighing inspirations shown in the respiratory record. They aid in marking the end of active respirations in the rapidly moving electrocardiographic film.

The normal electrocardiograms show the following type. The rate is relatively high, 109 per minute. The P wave is positive and sharply defined, the P–R intervals average 0.14 second. The ventricular complex begins with a sharp abrupt R wave of short duration and large amplitude. There is only a slight S wave. The T is diphasic, with a sharp negative deflection which ends in an abrupt positive, the two of about equal amplitude. The duration of the R–T interval is 0.24 second.

At 8 minutes 45 seconds the rate had increased to 150, with a shortening of the P–R interval to 0.112 second. At 9 minutes 30 seconds the rate was 156, P–R time 0.110 second. The R had increased in amplitude to 20 mm. against the normal of 17. The heart rate reached its maximum of 161 at 10 minutes, P–R 0.096 second, R–T 0.21 second.

At 10 minutes 30 seconds the heart rate was 159. P–R now 0.088 second, the shortest conduction interval shown in the tracing. The T wave was no longer diphasic but terminated in a sharp positive of 5 mm. From this point on until respirations stopped the T wave gradually and progressively increased in amplitude to a maximum of 11 mm. at 11 minutes 20 seconds, 4 or 5 seconds after the stopping of respiration. Beginning at 11 minutes, the rates computed from 10-second intervals are 145, 109, and

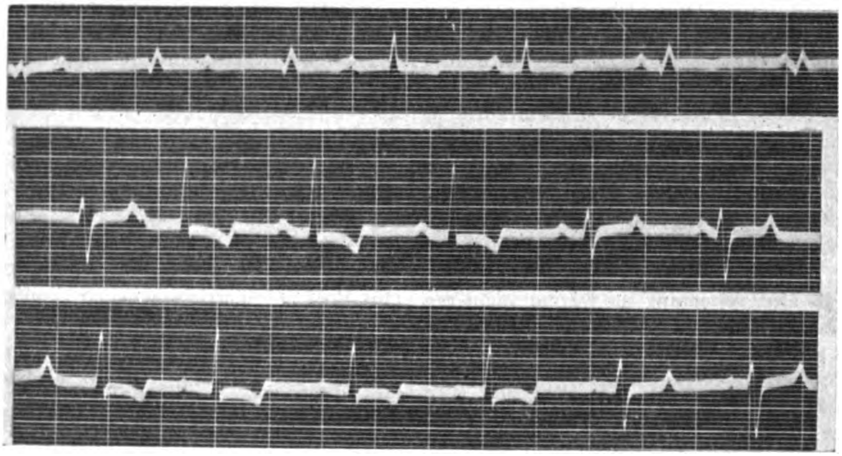


PLATE VI, FIGURE 43.—Electrocardiogram showing the displacement of the pacemaker to the left bundle branch in a dog under the influence of morphine. This experiment was obtained by Dr. Frank N. Wilson and Dr. George R. Hermann, by whose kind permission it is here reproduced. The three conventional leads are shown.

44. These changes in rate are accompanied by an increase in the conduction time as shown by the longer P–R intervals. The R wave decreased in amplitude through 19, 18, and 15 mm., respectively. During the 30 seconds of progressive slowing of rate the blood pressure fell. There was a corresponding increase in the pulse amplitude.

The first or right vagus nerve was cut at the point marked in Figure 39, Plate V, 11 minutes, 35 seconds. There were five slow swinging pulses just before the nerve was cut. Inhibition increased until the S–A rhythm gave place to an A–V rhythm, as shown in the last three complexes before the right vagus was cut. The last complex shows reversed sequence, the auricle contracting in response to A–V rhythm as in the human (2). (Fig. 9, Plate I.) When the first or right vagus was cut there was temporary release from inhibition to a faster rate and normal sequential beat. After two beats a 2–1 rhythm returned for five or six groups before complete block occurred.

The ventricular rhythm during the vagospasm was very regular, rate 44. The auricular rate was absolutely irregular. The P wave was positive throughout, but the P–P intervals have no regularity and cannot be lined with the ventricular complexes during this time. The intact left vagus does not inhibit the S–A nodal rhythm but it does block conduction.

On cutting the second or left vagus at 12 minutes 10 seconds the normal sequential type of electrocardiograms immediately returned, Figure 41, Plate V. The return rate was greatly augmented during the first few beats. This was without change in the P–R and R–T intervals but with a tremendous increase in the amplitude of the T wave.

Sequential beats after sectioning the second vagus ran a continuous series for 400 consecutive beats before rhythm suddenly ceased as shown in Plate V, Figure 42. During this series the rate progressively decreased. The electrocardiograms were remarkably regular and uniform in character. However, one striking phenomenon recurred here, namely, the augmentation of the T wave as direct cardiac anoxemia advanced. This phenomenon begins in this test early, by the reversal of the normal initial negative T. The amplitude rapidly increased at about the time respirations stopped. The T wave took on the tall type characteristic of A–V nodal rhythm during the vagospasm. When the second nerve was cut the T waves were at once almost as tall as the R waves and became taller to the end while the R waves progressively decreased.

BIBLIOGRAPHY.

(1) Greene and Gilbert: Arch. Int. Med., 1921, xxvii, 517.
(2) Greene and Gilbert: This Journal, 1921, lvi, 475. See also Arch. Int. Med., 1921, xxvii, 688
(3) Eyster and Meek: Heart, 1914, v, 119, 227.
(4) Mathison: Heart, 1910, ii, 54; Journ. Physiol., 1910, xli, 416.
(5) Lutz and Schneider: This Journal, 1919, l, 327.
(6) Hough: This Journal, 1911, xxviii, 369.
(7) Gasser and Loevenhart: Journ. Pharm. Exper. Therap., 1913, v, 239.
(8) Lutz, Gregg, and Schneider: This Journal, 1919, l, 228, 280. See also Gregg, Lutz, and Schneider: 216, 302.
(9) Ellis: This Journal, 1919, l, 267.
(10) Greene: In manuscript.
(11) Haggard: This Journal, 1921, lvi, 390.
(12) Greene: In manuscript.
(13) Cohn: Journ. Exper. Med., 1912, xvi, 732.
(14) Sherrington: Journ. Physiol., 1909, xxxviii, 381.
(15) Roaf and Sherrington: Quart. Journ. Exper. Physiol., 1910, iii, 209.
(16) Lewis and Mathison: Heart, 1910, ii, 47.

—By courtesy of the American Journal of Physiology.

A METHOD FOR MEASURING RETINAL SENSITIVITY.

By Capt. Percy W. Cobb, M. C., and Mildred W. Loring,
Medical Research Laboratory Air Service, United States Army, Mitchel Field, Garden City, Long Island, N. Y.

Acknowledgment.—The authors wish to acknowledge the courtesy of Nela Research Laboratories, for extending the facilities of the laboratory and permitting the expenditure of time, without which this paper could not well have been completed.

INTRODUCTORY.

In examining the candidate for flying status during the national emergency the search for a means of rating the visual capacity better and more complete than the usual letter test, recalled the fact, already known to workers in sense physiology, that attempts to measure visual sensitiveness to perception of small contrasts gave highly variable results, ambiguous unless time were taken to accumulate a large number of data, from which the effect of the variations could be eliminated by taking the average. The variations in such results are comparable, in their order of magnitude, to the very quantity which they measure, and the attempt to make such measurements, within the limits of time available and of equipment as yet adapted to the use of the opthalmologist gave results which were unsatisfactory and meaningless.

A test at one time experimentally practiced in the Air Service involved the use of a smoke wedge.[1] The subject was to draw the wedge slowly across a sight-hole until the test object ceased to be distinguishable. This latter was a 1-inch square of gray, mounted centrally upon a 2-inch square of lighter gray paper "where there are 13 perceptible differences between the two squares" (Nos. 32 and 19, respectively, in the series of papers in which white is No. 1, and black is No. 50). As a check, the same device was used, except that the smaller square was replaced by a 20/50 Snellen illiterate "E" of the same gray. This was the procedure for contrast sensitivity. For threshold sensitivity, the test object used was a 3-millimeter aperture in the iris diaphragm on the De Zeng stand, with specifications as to the lamp used and as to the general conditions of illumination of the room as they would affect the state of adaptation. In all cases the test was to be accomplished in not less than 5, nor more than 8 seconds, in order that the progress of adaptation of the eye during the performance of the test might not be too variable a factor in the result. Average results are in print.[2] Also certain results as to light and color threshold obtained under diminished oxygen during the rebreather test, but these are only stated in percentages based on the total number of cases, in which rise, fall or no change were found; and we are left to guess at the actual number of cases examined, and hence also at the significance of the results stated. The use of the wedge has since been abandoned for reasons which have just been mentioned.

Various letter charts, in which lines of letters are of uniform size, and are in graded degrees of contrast with the background, have also been tried. Notable, among these, is a set included in the work of DeWecker and Masselon, which one of us[3] once attempted to use. It soon appeared, however, that there were greater differences of visibility between the various letters of the same line than there were on the whole between the successive differently contrasting lines.

Nevertheless, since the ordinary Snellen chart, or other letter or character chart, measures minimal size while presenting maximal contrast, it is eminently adapted to estimating such factors as determine the geometric accuracy of the image, namely, the dioptric conditions of the eye, and it is only in a very incidental way, dependent upon the susceptibility of the retina itself to light or light changes. It apparently does not report changes or differences in retinal sensitiveness within the limits of normal function, and in disease of the retina the impairment in visual acuity is generally enormous. In short, with the test letters the retina is "everything or nothing," and it is this fact that leaves it to be desired that some method be devised which actually measures retinal sensitivity, both as to individual differences and as to functional differences within the individual.

The selection of the method used in the work herein described arose from consideration developed in a previous communication, to which the reader is referred for a fuller discussion.[4] Briefly, the plan of using a stimulus of minimal area and of minimal duration has been adopted and followed as the result of the consideration that these experimental conditions closely represent the common and usual conditions of retinal stimulation occurring in the course of ordinary critical eye work, and that these conditions are almost identical with those confronting the aviator or aerial navigator who is on the alert to detect an enemy air craft at the longest possible range. Stated in another way, the method rests upon the use of a stimulus which is within such limits of magnitude, both spatial and temporal, that it may physiologically be considered as being a point and existing for an instant of time, the only

[1] (*a*) Manual of Medical Research Laboratory, Washington, Government Printing Office, 1918, p. 140, and pp. 145, 146; also (*b*) Air Service Medical, same, same, 1919, p. 270, and pp. 275, 276. The text referred to in these two volumes is almost if not quite identical.

[2] Loc, cit., (*a*) pp. 288, 289; (*b*) pp. 158, 159.

[3] Cobb, Psychological Review, XXVI, 1919, p. 447 ff.

[4] Cobb, "The Momentary Character of Ordinary Visual Stimuli.' Psychobiology, II, pp. 237 to 244.

implication of this delimitation being the condition that within these limits the product of time and area shall, other things equal, be constant for a given sensory effect. That such a condition may be realized within limits will appear from what follows.

It is to be added, before proceeding with a description of the apparatus, that this method is perfectly applicable to the study of dark adaptation, with, of course, different limitations involving certain essential changes as to dimensions and as to general plan of construction, but without any change whatever as to the principle involved.

But since it is generally, if not universally, accepted that vision at comparatively high intensities of light or "day vision" depends upon organs anatomically distinct from those involved in "night" or "twilight vision" and concerned in dark adaptation, and since it is a fact that the two phases of vision so distinguished have quite different characteristics, it follows that the experimental findings derived from one of these conditions can not be used as a basis of rating with respect to the other.

APPARATUS AND METHODS.

The apparatus used in this work consists of an illuminated screen, S, Figure 2, 76 by 60 centimeters, with a small circular aperture at its center. The face of this screen is illuminated by two lamps, as shown in Figure 1a, at the same height as its center, 88 centimeters distant from each other and in a horizontal line 50 centimeters from the plane of the screen. Back of the central aperture and about 30 centimeters distant, is a small screen, S', Figure 2a, illuminated independently by a third lamp, L_3. The three lamps are 6 to 8 volt headlight lamps, vacuum type tungsten filament, the first two rated at 2½ amperes, the third at 2 amperes. The current was supplied by a motor-generator set rated on the generator side, for direct current, at 30 volts, 5 amperes, and at the low voltage used it carried the necessary current (about 6½ amperes) well. The generator being shunt wound, adjustment was effected by means of a rheostat which directly reduced the current in the field magnets, and only secondarily by resistance thrown into the external circuit. Slight fluctuations in the current were prevented by floating a battery of seven Edison alkaline storage cells on the line. (Eight cells would have served better.)

When the brightness of the small back screen is just equal to that of the main screen, the observer, sitting directly before the aperture, is not able to distinguish the latter at all, not even at fairly close range. If an opaque object be now interposed behind the aperture, the latter becomes, in appearance, a black dot. Experimentally, this condition was to be effected for very brief and measurable intervals of time. A gravity drop frame was constructed, indicated at D, Figure 2, and arranged so as to fall a fixed distance, in such a way that the aperture was not covered at any part of the drop, and was hence completely invisible to the subject when the frame alone was dropped. A detachable blind could be fitted into the frame to be carried with it in the fall and to pass behind the aperture, cutting off, during the time of passing, the light which had been reaching the eye of the subject from the back screen. This device was so constructed that the upper edge of the blind passed the aperture exactly at the instant when 115 mm. fall, from the starting point, had been accomplished, the lower edge having covered the aperture a brief interval of time before this. Thus the time of darkening of the aperture depended upon the height of the blind.

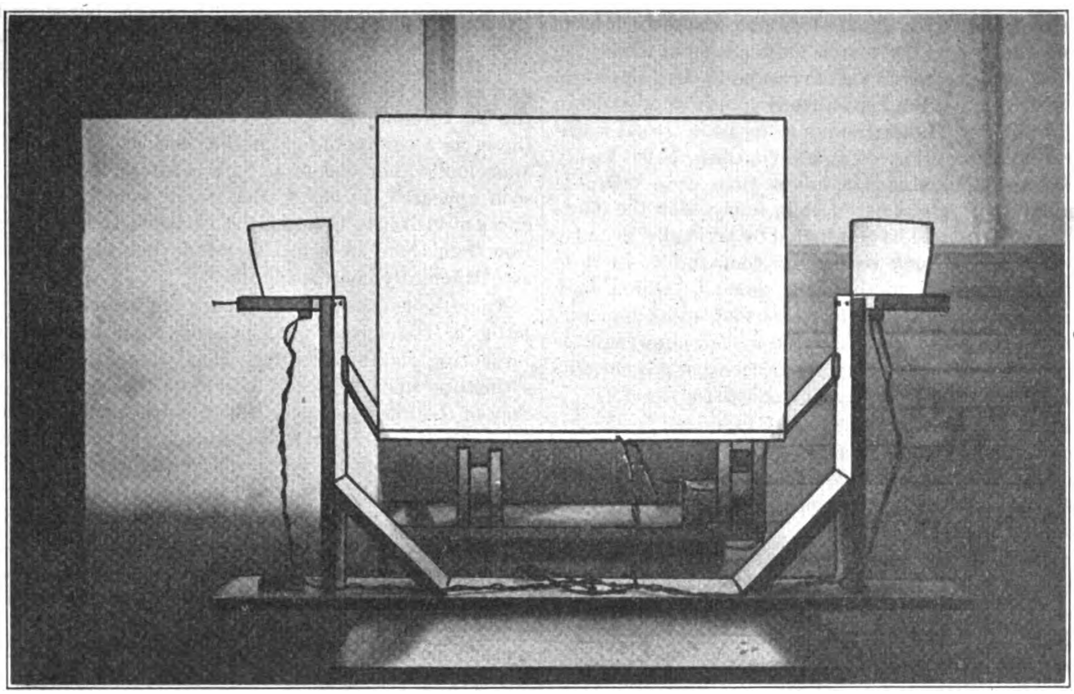


FIG. 1a.

The heights of the various blinds were computed to give a geometric series of time intervals corresponding to a series of numerical designations, according to the relation:

$$\text{time} = 200 \times (\tfrac{1}{2})^{N/6}$$

where N is the number of the stimulus and the time is expressed in units of 0.001 second (σ). Thus N, aside from being a convenient numerical designation, has also a definite relation to the time interval, and fractional values of N are intelligible by means of the formula. The stimuli actually used are included in Table I, where the time in σ, and the height of the blind in mm. are associated with the stimulus numbers. Blinds were constructed for all the numbers, but it was found by trial more expeditious to increase the interval between the stimuli of a series, so the even numbers were laid aside.

Two apertures of different diameters were used. These were punched in the exact center of cards 5 by 8 inches (127 by 203 millimeters) and fastened interchangeably at the center of the face of the screen S, especial attention being given to see that the aperture was in the correct relation as to height with the drop frame and laterally with the fixation point. A hole in the body of the screen was, of course, necessary. This was eleven-sixteenths inch ($17\frac{1}{2}$ millimeters) in diameter.

The diameters of the two apertures were measured from the cards actually used, twice in each of the four diameters at 45°, by the help of a microscope with a vernier micrometer stage and a micrometer eyepiece. The vernier read to 0.1 millemeters, and the measurements so made checked well with measurements similarly made from a pair of cards punched at the same time with the same punches, but never used. The average diameters were found to be:

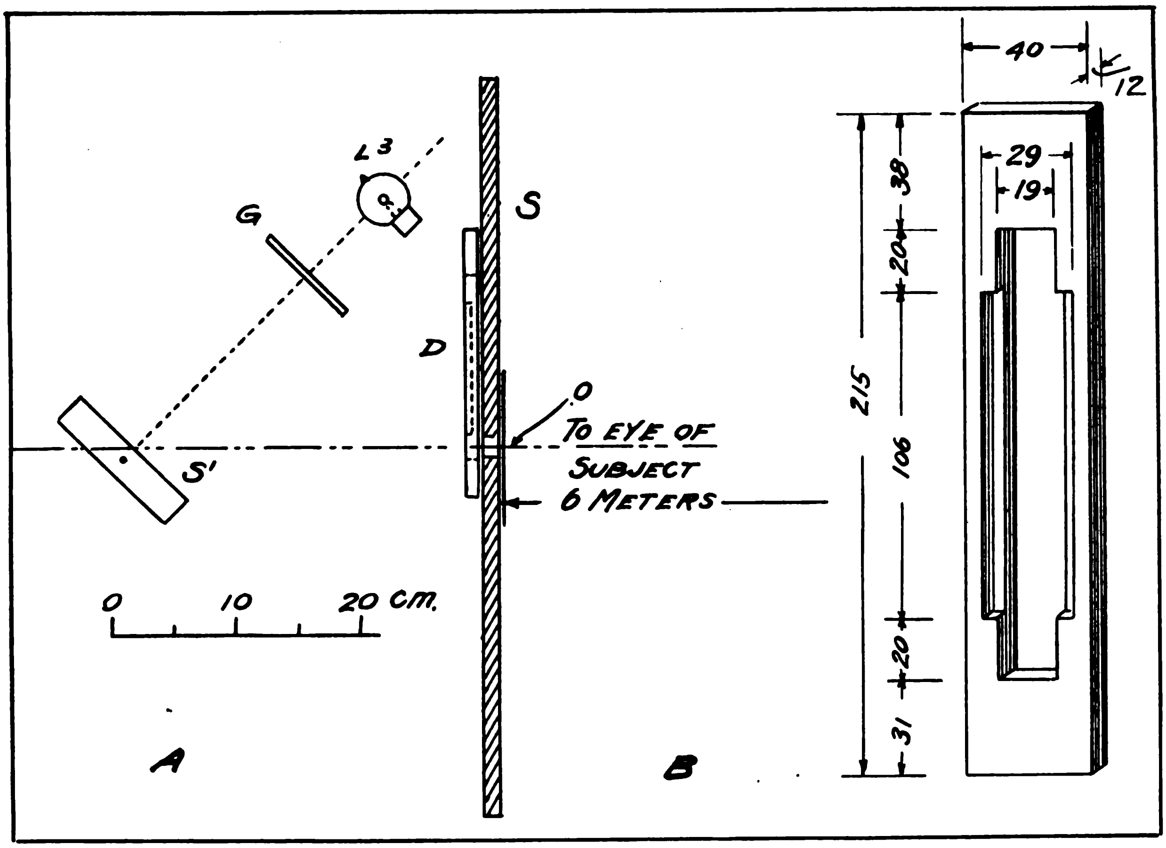


FIG. 2a.

TABLE I.

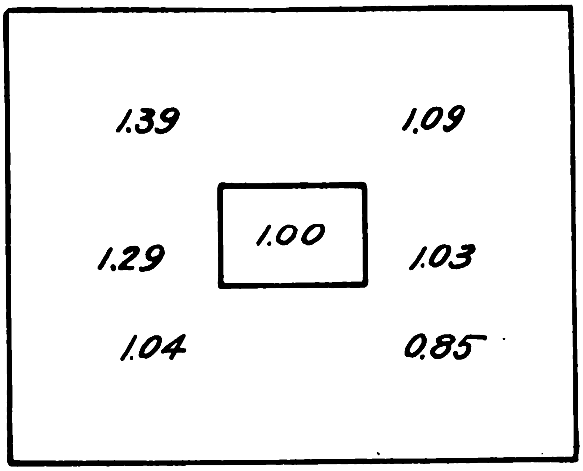
Stimulus No.	Time.	Width.	Stimulus No.	Time.	Width.
		Mm.			*Mm.*
7	109.0	105.4	29	16.2	23.1
9	91.7	96.5	31	13.6	19.6
11	77.1	86.7	33	11.5	16.6
13	64.8	76.7	35	9.6	14.0
15	54.5	67.2	37	8.1	11.9
17	45.8	58.4	39	6.8	10.0
19	38.6	50.6	41	5.7	8.4
21	32.4	43.5	43	4.8	7.1
23	27.3	37.3	45	4.1	6.0
25	22.9	31.9	47	3.4	5.1
27	19.3	27.1	49	2.9	4.3

	Cards used.	Not used (check).
	Mm.	*Mm.*
A and C	4.09	4.11
B and D	4.80	4.78

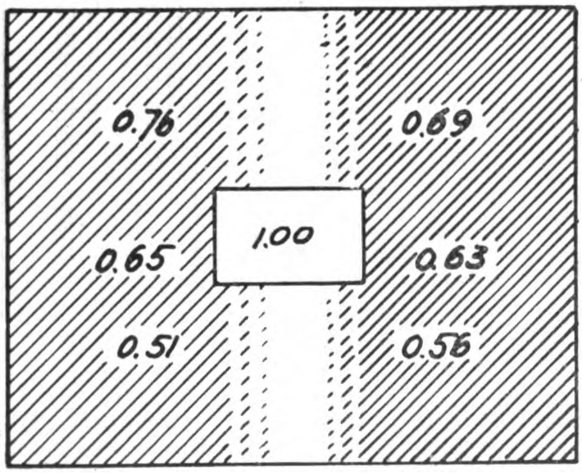
The corresponding areas are: A and C, 13.138 square millimeters; B and D, 18.096 square millimeters.

In order to show whether sensitivity was appreciably modified by minor differences in the brightness of areas

about the stimulus area, two slips of sheet metal were so placed that by their shadows the light from each of the pair of lamps was cut off from a portion (something less than half) of the main screen nearest to it as indicated in Figure 3a, leaving a central vertical band unshaded, sufficiently wide to make sure that the margin of the aperture was not touched by the shadows. The change in the distribution of light is numerically shown in the figure, which will indicate that the middle and upper parts of the screen were darkened to the extent of 40 to 60 per cent, the lower part only 30 to 50 per cent, of the central brightness. The



A AND B



C AND D

FIG. 3a.

shadows were used in the cases under the heads C and D. The four experimental conditions are thus summarized:

	Aperture.	Shadows.
A..........	Small.......	Absent.
B..........	Large.......	Do.
C..........	Small.......	Present.
D..........	Large.......	Do.

The screen was viewed by the subject at a distance of 6 meters, the position of his head being fixed by a Troland headrest. Fixation was made upon a point on the screen marked by a black-headed tack 21 centimeters (2° in the visual field) directly to the left of the aperture. The subject released the drop frame by touching a telegraphic key conveniently under his hand on the table to which the headrest was clamped. The center of the screen was kept as nearly as possible at a brightness equal to that of the test plate with 3-foot candles (32.3 meter candles) illumination upon it, which was (the reflection coefficient of the plate being 0.722)

$$\frac{32.3 \times 0.722}{\pi} = 7.42$$

candles per square meter. Readings were taken just before and at the close of each series and their mean was recorded as the exact value for that series. Photometric measurements were made with a Macbeth illuminometer.

PROCEDURE.

The current was adjusted so as to give as nearly as possible the standard photometric brightness at the center of the screen. This was done with the help of the photometer and the actual reading was recorded. The tendency to a slow and progressive change in the current was found to be minimized by so adjusting the rheostats that the battery was discharging into the line at the rate of two or three tenths of an ampere. The back screen was then adjusted to equal the main screen in brightness, i. e., so that the aperture disappeared for the subject. To accomplish this he sat with one eye in the line of experimental vision, the other closed, and at a distance of about 1½ meters, while the experimenter tilted the back screen until the opening was as nearly as possible invisible. If the experience of the subject were inadequate to make this method expedient, the experimenter performed the adjustment himself, and afterwards had the subject pass upon it. The absence of noticeable color difference made this method unobjectionable. The subject then took his place at six meters' distance and the series was begun At the close of the series a second photometric measurement was made and recorded as before. Four such series under conditions A, B, C, and D, in various orders, were run at one sitting and occupied about an hour.

The choice of a psychophysical method to be used in such work as this is largely a matter of excluding theoretically and practically objectionable features, and the discussion of the considerations which led to the choice and adoption of the one here used. and to the present mode of treatment of the results, would be too long to be included in the present communication.

There is comparatively little to be found in the literature upon the method of serial groups,[5] yet in the eyes of one who is interested in psychophysiology rather than in introspective psychology, this has an overwhelming advantage over other psychophysical methods in that it provides an immediate practical check on the subject in requiring him to react differentially to the stimuli and to the associated blanks in the same group.

The groups used consisted of 5 equal stimuli and 5 blanks, presented in shuffled order. For the blanks, in order that

[5] See Stratton, G. M., Psychol. Rev. IX, 1902, pp. 444 to 447, and Thomson, G. H., Br. Jour. Psychol., V, 1912-13, p. 204 ff. and p. 398 ff. Also Myers, A Textbook of Experimental Psychology, London, 1909, p. 209; same, 2d edition, 1911, Part I, pp. 196 to 197.

the motions of the experimenter should not be made the basis of reaction, a small horseshoe-shaped metal device was used to replace the blind, fitting into the drop frame in a similar way, but so formed that at no time during the fall of the drop frame did any part of it intervene between the aperture and the back screen. A fairly large stimulus was used in the first group, the number of the initial stimulus being later determined by previous experience. The subject had only to fixate the designated mark when the signal "ready" was given, release the drop by pressing the telegraphic key, and give his answer "yes" or "no" as to the adjudged momentary presence of the dot. If upon the first group a perfect score were given, the next group. involving a stimulus of one stage shorter duration, was given without pause; otherwise the next longer stimulus until a perfect score was rendered. The first perfect score being the starting point, consecutive groups were presented with stimuli diminishing step by step until a zero (or negative) score was rendered. This completed the series.

The descending order alone was used. The score for a particular stimulus was simply the number of "yes" answers given among the five answers to the stimuli, minus the number of "yes" answers (if any) given among the five answers to the blanks, and could possibly be anything from 5 to −5. Some subjects rarely failed to give correct interpretation to the blanks and rendered a zero score by replying "no" throughout the group. Others showed greater tendency to fail on the blanks and by the method used all were quantitatively "docked" therefor, resulting sometimes, but not frequently, in a score of -1 or -2 at the close of the series. The reason for this mode of rating should be obvious; we have no way of knowing whether the subject sees the stimulus except as we may infer it from the fact that his reaction to it is different from his reaction in the absence of it. We can agree with Myers that the positive reactions to the "catches" are interesting psychologically, but we can not agree with his statement that they are to be left out of account in the computation. The stimulus has been effective only in so far as the positive reactions to it have exceeded the positive reactions to the blank. The negative score is not troublesome if we remember that it is (so to speak) the obvious consequence of bad luck in guessing, and that in the long run this method of computing causes it and other unlucky guesses algebraically to offset the results of lucky guessing not otherwise detectable.

Estimating the threshold from the serial scores was accomplished by determining, by linear interpolation, that value of stimulus in terms of scale number which corresponded with a score of 2½ (50 per cent of a maximum of 5). In cases on inversion, where more than one such point was to be found, the first crossing of the 50 per cent point was interpolated (*a*) reading the series in the descending direction and (*b*) reading the series in the ascending direction. The mean of (*a*) and (*b*) was then accepted as the threshold for that series.

The performance of four series, involving the four conditions A, B, C, and D, occupied about an hour. The order of these was systematically varied from day to day.

The three subjects used are described as follows:

B.—A woman, age about 21, typist. Refraction not determined, but does not wear glasses nor show other evidence of visual defect. An ideal subject, in the fact that she renders prompt and definite judgments.

C.—Captain in the Medical Corps, United States Army, specializing in sense physiology, age 47. Astigmatism, well corrected, and moderate presbyopia. Vision, without glasses R. 20/50, L. 20/50 +. Wears: R: +1.75 cyl. ax. 92½°, V.=20/15; L: −0.25 sph. with +1.75 cyl. ax. 92½°, V.=20/15; with +1.00 sph. each eye, for near vision. As a subject, somewhat slow to react, but with experience in such work.

L.—A woman, age 28, psychologist. Vision 20/20+2/8 each eye. Does not wear glasses. Refraction, without mydriatic: R: +1.00 sph. with +0.25 cyl. ax. 82°, V.=20/15; L: +0.50 sph. with +0.25 cyl. ax. 112°, V.=20/15. Exophoria, 2 prism diopters at 6 meters. Experienced as a subject in psychological work.

The amount of experience as subject in this identical problem, prior to the work here recorded and incidental to the development of the method, is various for these three. B had about the equivalent of 12 series, C about 30, and L about 20. As nearly all of these were run before the method came into its present form, it is only in a rough way that an equivalent can be estimated.

Before computing the results a few of the series were deleted: (3 in the case of C, 1 in the case of L) where there was suspicion of an error in technic which did not permit of revision, or obvious disturbance of the subject, or, in one case, where the scores of the series gave evidence of some anomalous condition in the subject. In this last it turned out that the inclusion of this value would not have significantly altered the average.

The results of the remaining series were averaged, and in Table II are given: the mean threshold (N) and its probable error (E_N), and the number of terms (series) entering into the mean threshold (p).

TABLE II.

MEAN THRESHOLDS IN UNITS OF STIMULUS SCALE.

Small opening.			Subject.	Large opening.		
N.	E_N.	p.		N.	E_N.	p.
A. No shadows.				B. No shadows.		
22.63	0.32	(18)	B	26.05	0.19	(18)
26.31	.18	(21)	C	29.85	.37	(21)
22.37	.29	(20)	L	26.01	.18	(21)
C. With shadows.				D. With shadows.		
22.79	0.31	(18)	B	27.14	0.21	(18)
26.24	.24	(21)	C	29.17	.27	(22)
22.17	.17	(21)	L	26.96	.18	(21)

(*a*) SAME AS ABOVE. HUGE DEVIATIONS ELIMINATED BY CHAUVENET'S CRITERION.

A. No shadows.				B. No shadows.		
22.63	0.32	(18)	B	26.05	0.19	(18)
26.33	.14	(19)	C	29.85	.37	(21)
22.63	.27	(19)	L	26.18	.17	(20)
C. With shadows.				D. With shadows.		
22.79	0.31	(18)	B	27.32	0.18	(17)
26.05	.22	(20)	C	29.17	.27	(22)
22.17	.17	(21)	L	26.96	.18	(21)

Further, to reach group of results (A, B, C, or D) Chauvenet's criterion was applied, which resulted in further eliminations (1 in the case of B, 3 in the case of C, and 2 in the case of L). The averages from the remaining series are given under (*a*) in Table II.

RESULTS AND DISCUSSION.

The first question to be examined in the light of these results is the hypothesis implied in one of the introductory paragraphs of this paper. In these results, do the threshold times of exposure and the areas of aperture give equal products for the two cases? If it is true that they do, we should find the relation: $a_1t_1=a_2t_2$, or $\frac{a_1}{a_2}=\frac{t_2}{t_1}$; in which a_1 and a_2 are the areas of the two apertures and t_1 and t_2 the corresponding times of threshold exposure experimentally found. But it follows from the formula: $t=200\left(\frac{1}{2}\right)^{N/8}$ that: $\frac{t_2}{t_1}=\left(\frac{1}{2}\right)^{\frac{N_2-N_1}{8}}$, N_1 and N_2 being the two corresponding thresholds as found in terms of the stimulus scale. Hence: $\left(\frac{1}{2}\right)^{\frac{N_2-N_1}{8}}=\frac{a_1}{a_2}=\frac{18.096}{13.138}=1.3773$, from which we obtain, by means of logarithms: $N_1-N_2=3.695$.

This is the difference, on the stimulus-number scale, between the time thresholds for the smaller and larger apertures respectively, which is demanded by the hypothesis that the product, area multiplied by time, shall be constant for the threshold.

How far the experimental results go toward confirming the hypothesis from which the foregoing is, a priori, derived will be seen by a glance at the first three columns of Table III, where the average experimental differences are stated with their respective probable errors. The elimination of the widely deviating results by means of Chauvenet's criterion, it will be seen ((*a*) Table III), has not significantly altered the result. On the average the difference in scale units is 3.77, with a probable error ±0.14, or (*a*) with application of Chauvenet's criterion, 3.82 ± 0.14. The deviations from 3.695, the a priori value, being, respectively, 0.075 and 0.125, both lying well within the limits of the probable error. It is to be noted that there are items entering into the final average which depart rather widely from the anticipated result. These are under D–C, Table III, the comparison of the two apertures with the shadows on the screen. The departures of the experimental differences from the value 3.695 are here, for the several observers: B, 0.655 ± 0.37; C, -0.765 ± 0.36; L, 1.095 ± 0.25, all of which are seen to be larger than their respective probable errors. In connection with this fact, the further fact is to be noted that the results in the last three columns of the table all indicate that the presence or absence of the shadows was without significant effect, except in the cases under D–B (shadows compared with no shadows, larger aperture) where the differences are too large relatively to their probable errors to be considered insignificant. These differences, further, are all in the same direction as those just pointed out under D–C; each for each, and taken together, the two sets of results might be considered to indicate that the three observers differed most widely from each other in the case of the large aperture with shadows on the screen (condition D), since this is the experimental condition common to the two sets of differences, each of which, in detail, deviates from the general average in a corresponding way. This can be looked upon as presumptive but not as a definite conclusion, since the differences quoted are not large enough to put the matter beyond doubt.

TABLE III.

EXPERIMENTAL DIFFERENCES, IN UNITS OF STIMULUS SCALE.

Large versus small opening.			Subject.	Shadows versus no shadows.		
d.	E_d.	p.		d.	E_d.	p.
B–A. No shadows.				C–A. Small aperture.		
3.42	0.37	9.00	B	0.16	0.44	9.00
3.54	.41	10.50	C	−.07	.30	10.50
3.64	.35	10.24	L	−.20	.34	10.24
3.54	.22	29.74	Mean	−.05	.21	29.74
D–C. With shadows.				D–B. Large aperture.		
4.35	0.37	9.00	B	1.09	0.28	9.00
2.93	.36	10.74	C	−.68	.46	10.74
4.79	.25	10.50	L	.95	.25	10.50
4.00	.19	30.24	Mean	.41	.20	30.24
All results.				All results.		
3.77	0.14	59.98	Mean	0.19	0.14	59.98

(*a*) SAME AS ABOVE. HUGE DEVIATIONS ELIMINATED BY CHAUVENET'S CRITERION.

B–A. No shadows.				C–A. Small aperture.		
3.42	0.37	9.00	B	0.16	0.44	9.00
3.52	.39	9.97	C	−.28	.25	9.74
3.55	.32	9.74	L	−.46	.32	9.97
3.50	.21	28.71	Mean	−.20	.20	28.71
D–C. With shadows.				D–B. Large aperture.		
4.53	0.35	8.74	B	1.27	0.26	8.74
3.12	.34	10.47	C	−.68	.46	10.74
4.79	.25	10.50	L	.78	.24	10.24
4.12	.18	29.71	Mean	.40	.20	29.72
All results.				All results.		
3.82	0.14	58.42	Mean	0.10	0.14	58.43

So far this discussion has been limited to the consideration of the effect upon the time value of the threshold of the two experimental variables purposely introduced. These are the area of the stimulus-opening, and the presence or absence of shadows upon the screen. In addition to these there are three other variables incidental to the experimental procedure, which, including the principal variable, namely, the threshold itself, are listed as follows:

(1) The time threshold. This is the stimulus number reduced, for the purpose of correlation, to an intercomparable value by expressing the result of each series in terms of the mean of the group taken under identical conditions. Symbol, T/M.

(2) The ordinal number of the series in the group of four taken at a sitting.

(3) The ordinal of the sitting in the group of 18 to 22 taken under identical conditions.

(4) The mean photometric brightness of the field immediately surrounding the test-stimulus.

In what follows these quantities are designated by subscripts corresponding to the numerals above.

These four variables are correlated by Pearson's method,[6] two and two, and from the six correlation coefficients of the zero order, so obtained, the partial coefficients of the second order were computed. These, with their probable errors (E_r), are as follows:

Subject.	B		C		L	
	r	E_r	r	E_r	r	E_r
$r_{12.34}$	0.037	0.080	0.098	0.074	−0.362	0.065
$r_{13.24}$	−.046	.080	.082	.074	.125	.074
$r_{14.23}$	.311	.072	.115	.076	.174	.073

Similarly the standard deviations of the four variables of the zero and second orders are:

	B		C		L	
	Zero order.	Second order.	Zero order.	Second order.	Zero order.	Second order.
1	0.065	0.062	0.057	0.056	0.053	0.049
2	1.11	1.07	1.13	1.12	1.12	1.04
3	5.2	5.0	6.4	6.3	6.0	5.9
4	.12	.11	.11	.11	.087	.085

And the characteristic equations derived from these, for the three subjects, are stated as follows:

$$\text{B: } x_1 = 0.002\,x_2 - 0.0006\,x_3 + 0.18\,x_4 \quad E = \pm 0.042$$
$$\text{C: } x_1 = .005\,x_2 + .0007\,x_3 + .06\,x_4 \quad \pm .038$$
$$\text{L: } x_1 = .017\,x_2 + .0010\,x_3 + .10\,x_4 \quad \pm .033$$

In these equations the various x's have reference to differences or variations in the corresponding variables—or perhaps better, we may say that x represents the deviation of the variable from the mean of all its experimentally measured values in units the same as those in which the corresponding quantity is expressed.

If we wish to estimate the extent to which x_1 is influenced by the deviation of any one of the other variables, say x_2, from its mean value, we must substitute that deviation of x_2 for x_2 in the equation and put x_3 and x_4 equal to zero. From inspection of the equations, it will thus appear that x_2 is most significant in the case of subject L. An idea of its importance in these results may be gained by substituting for x_2 its standard deviation (1.12) and we have $x_1 = -0.017 \times 1.12 = -0.019$. Which is to say that in this case fluctuations in the value of T/M (x_1) are introduced by the fact that subject L gave higher results early in the experimental sessions and vice versa, and that the effect of these fluctuations upon her results are represented by a standard deviation of T/M equal to 0.019. This is equivalent to 0.42 or 0.50 in "Stimulus number" (Table I) according as we refer it to the threshold obtained with the small opening (average 22.27, Table II) or the large opening (average 26.48). A representative range of fluctuation due to this cause might be taken as twice this or roughly one number on the scale, if we look upon the fluctuations as centering at the mean, and characteristically extending by an amount equal on the whole to the standard deviation in either direction therefrom. When we investigate in the same way the serial number of the day, the same subject shows the largest deviation: $0.0010 \times 6.0 \times 2 = 0.012$, indicating that the representative practice effect for the whole period of experimentation is small, less than one-third of one scale unit. This is, perhaps, not surprising, in view of the fact that each of the three subjects had had practice with the method before any of these recorded results were taken.

The deviations of the photometric value of the test field, x_4, have not, except in one case, produced any noteworthy disturbance in this work, but such disturbance as is shown, taken together with other considerations, makes the photometric control of the conditions a precaution carefully to be considered. From the characteristic equations, we have, similarly to the foregoing, the disturbance due to photometric fluctuation:

	In terms of T/M.	In scale units.
For B, $0.18 \times 0.12 \times 2 =$	0.043	0.97 to 1.14
C, $.06 \times .11 \times 2 =$	.013	.34 to .38
L, $.10 \times .087 \times 2 =$	.017	.38 to .45

While, in scale units, these deviations are not larger than the deviations due to variables 2 and 3, i. e., those defining the place of the series in the experimental order, it must be emphasized, first, that the variations in the photometric values themselves (x_4) are small, being no more than the unavoidable variations in the adjustment of the apparatus to an exact value, but they are still large enough to measure. The largest value of the standard deviation is 0.12 apparent foot candles (in the cases of B and C), which means that while 3 apparent foot candles was the brightness aimed at, the actual brightness fell about as often within the limits 2.92 to 3.08 ($3.00 \pm 0.6745 \times 0.12$) as it fell outside of these limits. These limits are the exact value attempted, plus and minus its probable error computed from the actual results.

The second point to be emphasized is, that if this measure of retinal sensitivity is to be used as a test, the apparatus must be checked against a standard light-source, by means of a photometer, and corrected as often as necessary as the work proceeds. The mean coefficient of x_4 in the three characteristic equations is 0.11 and the corresponding coefficients of correlation (14.23) are large enough to be significant. This means that within the present limited range of the actual photometric settings, the measure of sensitivity of the individual changed at the rate of 11 per cent (1½ to 3 numbers in the various cases) per apparent foot candle. While it is not correct to extend the application of this rate of change beyond the range for which it was actually found to exist, it must nevertheless be remembered that the voltage in the usual lighting circuits is often a highly variable quantity; that the percentage change of the candle-power of an electric lamp is several times the corresponding percentage change in

[6] As described by Davenport, C. B., Statistical Methods, 3d ed. New York, p. 44. The mathematics involved in the discussion is treated by Yule, G. U., Theory of Statistics, London, 1919, chap. 12.

voltage; and that an individual lamp operated at its rated voltage is a changing and not a constant source. Such amps are usually designed and rated to operate 1,000 hours with 20 per cent drop in candle power during that period. Twenty per cent of the present screen brightness is 0.6 apparent foot-candles, which would, on the average, condition a drop of 0.066 in T/M, or a drop of nearly 2 scale-units in retinal sensitivity. And this is nothing as compared with the errors that would have been introduced by depending upon a line-voltage characterized by such fluctuations as those existing at Mitchel Field at the time this work was done.

Another consideration, which led to the installation of the motor-generator and battery used in the present work, was the possibility of errors due to the use of the alternating current. Although ordinarily appearing to give a steady light, electric lamps, and especially those of the lower wattages and therefore more slender filaments, undergo rapid fluctuations in candle power synchronously with the alterations of the current. On a 60-cycle current the dim (or bright) phases occur at the rate of 120 per second, or at intervals of 8.3σ. Stimulus No. 22 has a duration of 29.7σ, No. 29, 16.2σ. It seemed clear in advance, that the fluctuations in the light from a lamp on the alternating circuit might introduce errors, variable in amount according to the exact phase of the current in which the shutter was dropped. The use of the direct current evaded this dubious condition; and the use of automobile lamps, designed for low voltage and high current, and consequently having filaments too coarse to readily follow, in temperature, any sudden and slight fluctuations of the current, was especially favorable from this standpoint.

SUMMARY.

1. A threshold method of measuring retinal sensitivity is proposed, by which a stimulus of very small and fixed extent is exposed for a very short measured time. The stimulus is physically a negative one, by which is meant that it appears as a black dot upon a white screen.

2. The psychophysical method of serial groups was used, each series of groups furnishing one datum. The basis of the conclusions is 240 such series, about equally divided among the three subjects.

3. It was found that the product of the time of exposure multiplied by the area of the stimulus was constant on the average at the threshold. This applies to the two apertures used, of 13.138 and 18.096 square millimeters area respectively, observed at 6 meters distance.

4. For the several observers the average threshold time, reduced to its equivalent with a standard opening (area= $10\sqrt{2}$ square millimeters), was found to be: B, 25.7 σ; C, 19.5 σ; and L, 26.2 σ.

5. Shadows covering the major part of the screen, but not the working area immediately about the stimulus, by which 40 to 60 per cent of the light was cut off, did not significantly alter the time necessary for effective stimulation.

6. The place of the series in the succession of the usual four run at one session did not appear, except in one case, to be of significant effect upon the threshold time. The correlations were dubious in the other two cases. In the one case in question, a manifest hyperopia of one diopter and of one-half diopter was demonstrable in the two eyes respectively, and sensitivity appeared to grow less during the progress of the day's series.

7. The serial place of the day in the whole course of experimentation was of negligible import, except possibly in the case of the same observer, where the coefficient of correlation (second order) was 0.125 ± 0.074, and no more than a minor effect upon the result was indicated.

8. There appeared to be a fairly definite and constant correlation between the threshold time and the unavoidable but measurable variations in the photometric brightness of the screen in the direction of decreased threshold time with increased brightness. This was minimized in the experimental work by careful measurement and adjustment of the brightness. This result justifies the photometric precautions used and indicates the absolute necessity of careful photometric control in any application of this method of retinal sensitivity measurement.

EXPLANATION OF TABLES.

TABLE I.—The arbitrary scale of stimuli (stimulus number), the duration of each (time, σ), and the vertical length (width, mm.) of the corresponding blind calculated to conclude the required period of time just as the drop frame has completed 115 millimeters of free fall.

TABLE II.—The average results, for each of the three subjects. The small opening has an area of 13.138 square millimeters, the large one 18.096 square millimeters, both seen at 6 meters distance, at the center of a white screen 60 by 76 centimeters, fixation 2° to the left of the (central) opening.

N.—Average threshold, arbitrary scale. Compare Table I.

E_n.—Probable error of the same.

p.—The number of series upon which the above are based.

TABLE III.—The differences on the arbitrary scale, due to the use of the large or small opening and those due to the presence or absence of shadows. Compare Table II.

d.—Experimental difference, arbitrary scale.

E_d.—Probable error of the same.

p.—Weight of the result, the weight of a single series being unity.

LEGENDS TO FIGURES.

FIG. 1.—General view of the apparatus, about as seen by the subject.

FIG. 2.—A, diagram of the apparatus; B, detail of the drop frame (D), with dimensions in millimeters.

FIG. 3.—The relative photometric brightness at various points on the screen, and the distribution of the shadows in cases C and D.

—By courtesy of the Journal of Experimental Psychology.

INDIVIDUAL VARIATIONS IN RETINAL SENSITIVITY, AND THEIR CORRELATION WITH OPHTHALMOLOGIC FINDINGS.

By Capt. Percy W. Cobb, M. C., *Medical Research Laboratory Air Service, United States Army, Mitchel Field, Garden City, Long Island, N. Y.*

Acknowledgement.—The author wishes to acknowledge the help of Dr. Mildred W. Loring and Miss Elizabeth K. Stark in the performance of most of the technical work of accumulating these results; the help of Miss Marion L. Smith in performing the computations; and the courtesy of Nela Research Laboratories in facilitating the completion of the manuscript.

The method by which the measurements of retinal sensitivity were made, which are the subject of this communication, has in its essential details already been described.[1] The purpose of the present paper is to investigate primarily the significance of the results obtained by the method, and secondarily its applicability as a test in the routine examination of candidates for flying status in the Air Service. Measurements were made upon a group of 101 subjects. Visual acuity was measured in nearly all of these for each eye separately and for both eyes together by means of the Snellen letters under the actual conditions of the experiment; and in addition, the complete findings of the routine ophthalmological examination for flying status upon 59 of these subjects for the purpose of comparison.

The group consisted of such individuals as were available, and without specific enumeration may be described by noting the classes into which they might be grouped, in the order of their relative numbers: (1) Enlisted men of the Army, a few from the Navy, some recruits and some civil candidates for the cadet school of aviation; (2) a number of flying officers; (3) a number of other officers, chiefly of the medical corps of the staff of the Medical Research Laboratory or there present for instruction; (4) a few civil employees of the laboratory (including four women), technical, clinical, and one skilled mechanic.

The present method of estimating retinal sensitivity is, essentially, to determine the duration of exposure of a black dot at the center of a white screen, necessary in order that the dot may just be seen. The actual dimensions of the dot and the distance of the subject from the screen are kept constant, as is also the photometric brightness of the screen. The dot is formed by a small circular aperture in the screen, through which a secondary screen, behind the other, is seen, and the screen behind is so illuminated that its appearance is an exact match with the margins of the aperture. When this is accomplished the aperture disappears. It becomes in appearance a black dot when an opaque object cuts off the light coming through it, and the necessary time of darkening, in order that the dot may be perceived with 50 per cent certainty, is the quantity measured.

[1] Cobb and Loring, Jour. Exp. Psych. 1921.

The usefulness of a new test may depend upon one of two circumstances. It may be supplementary to tests already in use (*a*) in a confirmatory sense, or (*b*) it may measure something not already taken into account by tests currently used. It may be useful in either case. Intrinsically, a test must show, by the results that it gives—(*c*) that it actually does give a measure of something worth knowing, and (*d*) it must give a fairly reliable result. This last (*d*) has been accomplished, if measurements on the same individual, under conditions as nearly the same as practical considerations warrant, will, at different times, give not too widely divergent results. The condition (*c*) is met (granting that we aim to test individuals) if results from different individuals prove to be different by variations of a larger order of magnitude than the variations in the same individual under identical conditions. If we aim to detect changes in the sensitivity of the individual, the condition (*c*) will have to be met somewhat differently.

The first point to investigate is the reproducibility of the result. It was shown in the previous communication upon this method, that for the three subjects, each having had some practice as such, the variability of the result of a single series, representing about fifteen minutes' expenditure of time, was represented by a probable error of one unit or less on the arbitrary scale, equivalent to not more than about 8 or 9 per cent in actual time.[2] The figures are given here in Table I.

([2]). The relation between T (stimulus number) and t, the time of exposure (thousandths of a second), is given by the formula: $t = 200 (\frac{1}{2})^{T/8}$. An extract from the original table embodying this relation is given here:

T.	Time.	T.	Time.	T.	Time.	T.	Time.
20	35.4	22	29.7	24	25.0	26	21.0
21	32.4	23	27.3	25	22.9	27	19.3

From these can be obtained the time values corresponding to the other numbers, if we remember that an increase of 8 units in T means that the time is divided by 2 and vice versa.

Furthermore, owing to the fact that the screen opening (area, 14.421 square millimeters) was somewhat different from its designed size (10.2 square millimeters) a slight correction is necessary to reduce the values for the group of subjects treated in this paper to standard conditions. This correction (to be perhaps unnecessarily accurate) consists in decreasing T by 0.22; or increasing the time by 2 per cent.

Table I.

Subject.	T.	s T/M.	E.	Time thousandths.	
				Mean.	Limits of P. E.
B.......	23.70	0.062	0.99	25.7	23.6 to 27.9
C.......	26.85	.056	1.01	19.5	17.9 to 21.3
L.......	23.48	.049	.78	26.2	24.5 to 28.0

This would be considered good reproducibility for such work as the present. But it must be remembered that these subjects were all more or less practiced in the method before the above results were obtained.

Before considering the results of the group, it may be well to examine the measurements taken from the above three subjects in another respect. The question arises in connection with a test of this sort, not only what will happen when a measurement is attempted upon a new and unpracticed subject, but also what happens in the case of any subject, practiced or not, when several series are run in succession. There is the possibility of a fatigue effect, or of an effect of learning or practice. These two may be expected to affect the result in opposite ways and may predominate, one or the other, irregularly, or may possibly tend to offset each other.

The average results for the three subjects first discussed follow, accompanied by the number of items entering into the average and by the mean variation. The average values (M) are all in the neighborhood of unity, because, for the purpose of comparison, each item was, before averaging, divided by the mean of all results (T) for identical physical conditions. The figures given, both threshold and mean variation, are therefore expressed in terms of the general mean. Similar results for a group of 33 unpracticed subjects (the first of a group of 96 subsequently to be discussed) appear in the fourth line. Here each item has been reduced to the average of the individual's four consecutive series as unity.

Table II.

Subject.	Series 1.			Series 2.			Series. 3.			Series 4.		
	N.	M.	MV.	N.	M.	MV.	N.	M.	MV.	N.	M.	MV.
B............	18	0.996	0.048	18	1.002	0.069	18	1.003	0.049	18	0.993	0.037
C............	22	.985	.057	22	.998	.058	22	1.005	.042	22	1.012	.046
L............	21	1.016	.058	21	1.020	.036	21	.981	.042	21	.964	.030
Various......	33	.993	.044	33	.992	.046	33	1.019	.054	33	.996	.050

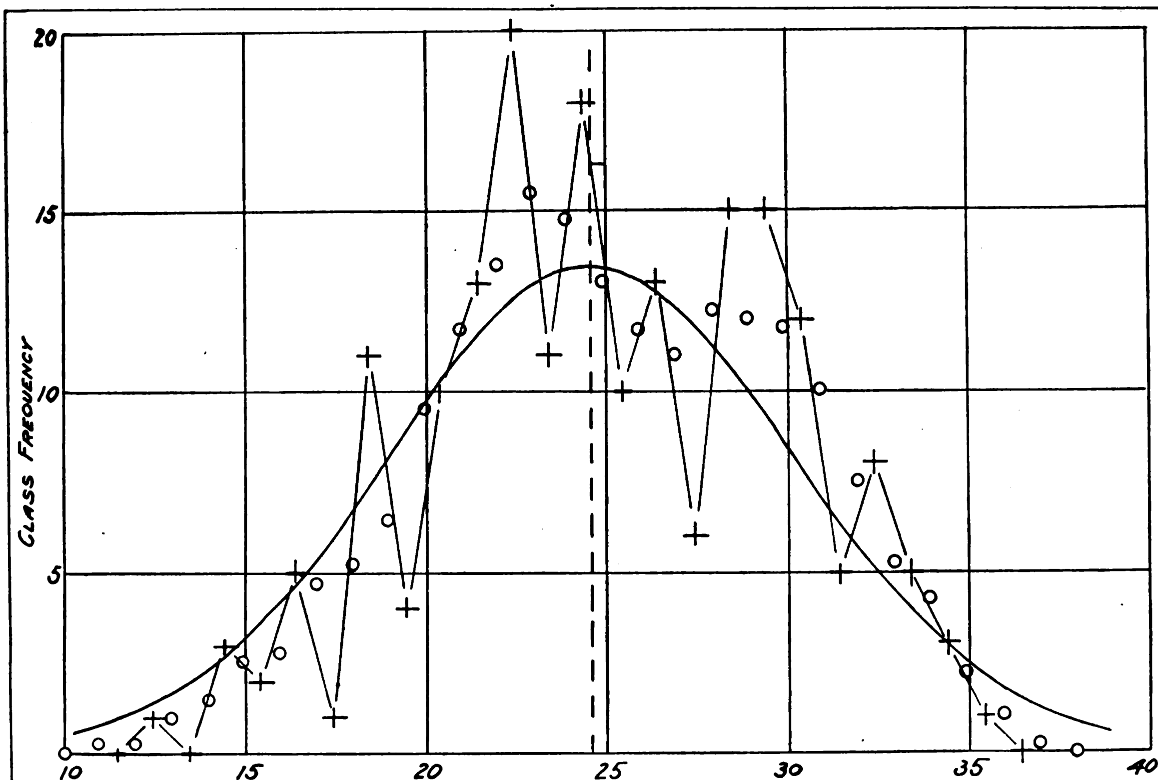


FIG. 1. THRESHOLD (T)

It will appear from the above that on the whole the variabilities of the successive results diminish somewhat, although in the case of the unpracticed subjects the change is in the opposite direction, but not to a significant extent. It appeared, however, that it would be out of the question, in using the method as a test, to expend the time necessary to run four or even three series as a routine matter. That consideration will therefore be dropped, and only the first and second series will be considered in what follows.

The 33 subjects just mentioned were the first of a series of 101, which will form the basis of the major part of this discussion. Visual acuity was taken, at the time of the retinal sensitivity measurement, in 100 of these with each eye separately, and in 91 of these, with both eyes together. Unfortunately, in 5 cases of the 91, retinal sensitivity proved to be too low to measure with the apparatus as constructed, and rather than deviate from the established technique, it was decided to record these simply as "too low to measure." Some idea of the probabilities in these five cases may be gained from the fact that the lowest measurement actually made in conformity with the established technique was T = 12.7, and the three next 14.3, 14.5, and 14.7, respectively.

The distribution of 192 measurements, two upon each of 96 subjects, is shown in Figure 1. The small circles represent values of the "sliding" averages of four of the original class-frequencies and the smooth curve is that of a normal distribution based upon characteristics of distribution derived as follows: (1) A mean drawn from the whole of the 192 measurements less the 10 highest, omitted to offset the absence of the corresponding 10 lowest of 202 possible measurements, which are not included in the 192 because of their being too low to measure; and (2) a measure of dispersion derived from the sum of the deviations of that fraction of the distribution lying above the mean.

The first of the curves in the diagram (a) exhibits irregularities due to the method of interpolation by which a numerical threshold was derived from the results of one series. This method favored the even integers; that is, of the 192 interpolated values, 119 were even integers plus a fraction, and 73 only were odd integers plus a fraction. Inspection of the figure will show this irregularity. However, the circles representing the average frequency of four consecutive classes, plotted against the average of the corresponding four class-types, represent values from which this systematic irregularity is eliminated, and among which other irregularities are also, in part, evened out. Nevertheless, in comparing the line of the circles with the curve of normal distribution, it would appear that there are in the former two maxima: one at about the point where T=23, ($t=27\sigma$) another at T=29, ($t=16\sigma$); with a minimum between them T=27, ($t=19\sigma$). In other words, the plot suggests very strongly that the distribution of results is a bimodal one.

The relation existing between the results of the first and second series on each of the 96 subjects is shown in Figure 2, where the second of these is plotted directly against the first. The two means are I, 24.91 and II, 25.17; very close together. The oblique dotted line, drawn at 45° inclination, is the locus of the cases in which the two are exactly equal. The mean values just stated would indicate a tendency in the subjects to go higher on the second series, and a glance at the figure will show this tendency in general to be greater in those above the mean than in those below it and, in fact, to be reversed in a few cases at the other extreme. This shows itself also in the two standard deviations. That for the first series is 4.6, for the second 5.1. The correlation ratio is 0.857 ± 0.018.

The characteristic equations derived from the above are:

$$x_1 = 0.77x_2,\ E_1 = 1.6;\ \text{and}$$
$$x_2 = 0.96x_1,\ E_2 = 1.8,$$

in which the two probable errors (E) may be taken as an index of the variability of these inexperienced subjects, as a group, for the first and second consecutive trials, respectively. This indicates a lower degree of reproducibility for the group of 96 subjects than for the three considered in Table I. There the values for E are of the order of 1 or less. The group of 33 various observers will be seen to compare very favorably with the three observers, B, C, and L (Table II, M'V's).[3] They therefore appear to show a better reproducibility than the group of 96 as a whole, of which they are a part.

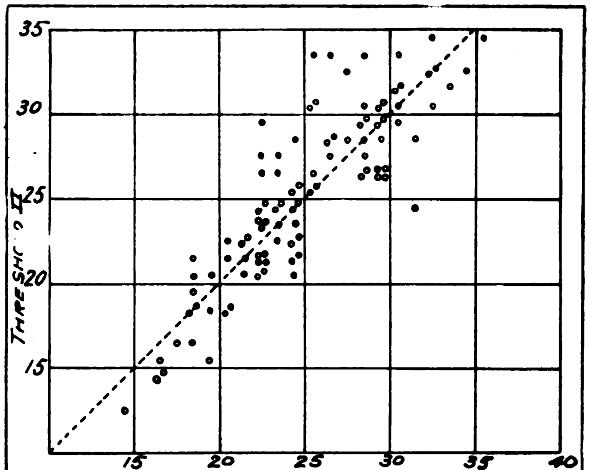


FIG. 2 THRESHOLD I

This is incidental to the rather unusual way in which the method of correlation[4] has here been applied, for the purpose of estimating from the results of a group the expected standard deviation of repeated identical measurements upon an individual. In plotting the second set of results, b, against the first (a) as abscissæ, it will be seen that although the a's are of identical class type for any column of b's, yet in the case of any pair plotted in the column, the a is still in every case a variate from a possible mean, from which it deviates on the whole by an amount represented by its own standard deviation. Thus the standard deviation from their characteristic line of the b's ($\sigma_{2.1} = \sigma_2\sqrt{1 - r^2_{12}}$) is not the standard deviation to be expected of repeated identical measurements, but is greater than the latter, as the standard deviation of a (sum or) difference exceeds that of either term; by the factor $\sqrt{2}$ when the two are of equal variability. Accordingly the two E's stated above should be divided by $\sqrt{2}$, and they then become $E_1 = 1.1$, $E_2 = 1.3$, which conform fairly well to the results stated in Tables I and II.

[3] The probable error for all results of the group of 33, Table II is 1.05, on the same basis as the values for E in Table I, for subjects B, C, and L.

[4] The correlations discussed here were performed by Pearson's method.

Of especial interest in determining the value of this test is the question of the correlation existing between its results and those of the ophthalmologic tests. And of these the relation with visual acuity taken by the Snellen letters was of especial interest. Visual acuity was taken for each eye separately and for binocular vision by hanging a test letter card upon the screen of the apparatus, so that the conditions of the retinal sensitivity test were exactly reproduced for the letter test. The results of the correlations performed by Pearson's method are given in Table III.

TABLE III.

(*a*) Numerical designations of the variables:

1. Retinal sensitivity (mean of I and II series).
2. Visual acuity (Suellen), binocular vision.
3. Same, better eye alone.
4. Same, poorer eye alone.

(*b*) Correlation-ratios:

ss.	N.	r, zero order.	E_r.	ss.	r, first order.	ss.	r, second order.
12	86	0.375	0.062	....	....	12.34	0.177
13	95	.321	.062	....	....	13.24	−.068
14	95	.355	.060	....	....	14.23	.147
23	91	.871	.017	23.4	0.716	23.14	.716
24	91	.723	.034	24.3	.191	24.13	.160
34	100	.760	.029	34.2	.384	34.12	.389

(*c*) Standard deviations:

ss.	N.	σ, zero order.	ss.	σ, second order.	ss.	σ, third order.
1	95	4.62	....	....	1.234	4.24
2	91	.271	2.34	0.131	2.134	.129
3	100	.275	3.24	.125	3.124	.125
4	100	.247	4.23	.157	4.123	.155

An incidental question, worked out by way of side issue, is the relation of binocluar visual acuity (V_0) to the two values of monocular visual acuity obtained with the better eye, (V_1) and the poorer eye (V_2) respectively. The equation for this value, derived from the correlation-ratios of the first order and the standard deviations of the second order, involving the variables 2, 3, and 4 only, is as follows:

$$V_0=0.75\ V_1+0.16\ V_2+0.18 \qquad (1)$$

the standard deviation of V_0 is $\sigma 2.34=0.13$. It is to be remembered that the bulk of the results fell about the region of V=20/30 to V=20/15 (6/9 to 6/4.5 metric or 1 to 1.33 decimal) and the application of this equation is not safely to be extended outside these limits.

The interpretation of a characteristic equation such as the above is that V_0, calculated from the observed values of V_1 and V_2, is the expected value of binocular acuity, and that experimentally determined values may be expected to deviate from this as implied in the accompanying standard deviation, $\sigma 2.34=0.13$.

Similarly, the characteristic relation between retinal sensitivity (T) and the three values of visual acuity above enumerated is:

$$T=5.8\ V_0-2.3\ V_1+4.0\ V_2+16.2 \qquad (2)$$

and the standard deviation of T is $\sigma 1.234=4.24$; the same reservations as to the limits of applicability of this equation to apply, as in the case of equation (1).

These relations exhibit one or two points worthy of note. From equation (1), it will be noted that binocular visual acuity depends in a major degree upon the vision of the better eye. Whether it depends at all upon the vision of the inferior eye is an important question. V_2 being ordinarily somewhere about unity, the value of the V_2 term will be about 0.16, which is not greatly in excess of the standard deviation of V_0 from its value computed by the equation. However, while the plotted results show many cases where binocular vision was distinctly better than the vision of the better eye alone, there are but 4 cases in a total of 91 where the reverse is true, and this only to the extent of one class interval, equal to two single letters on the chart, or decimally expressed, equal to a difference of from 0.04 to 0.15 according to the portion of the chart involved. The mean value for V_0 is 1.22; for V_1, 1.16; and for V_2, 1.06; which also would indicate a definite extent to which, on the average, vision of the one eye is helped by the second, inferior, eye in binocular vision.

As to equation (2), the negative coefficient of V_1 would seem to indicate that the better eye has a negative contributory value to retinal sensitivity. By the same reasoning as the foregoing we see that in general the amount of the second term, V_1 being about unity, does not exceed the standard deviation of T (4.24). We must also bear in mind that the three V's bear high correlations, each to the other. The writer would interpret the equation as meaning that the better eye contributed to the result in the case of retinal sensitivity (that is, reinforced the poorer eye) only in so far as it does the same with reference to the letter chart; that is, only in so far as it cooperates with its inferior fellow in other respects. Retinal sensitivity is shown by the equations to be more highly dependent upon V_0 than upon either V_1 or V_2; which is perhaps to be expected, for retinal sensitivity was also taken binocularly.

This equation answers the question as to whether this test is to be looked upon (as indicated in an early paragraph of this paper) as supplementary to other tests in (*a*) a confirmatory sense or (*b*) as measuring something not already taken into account.

For the measures of retinal sensitivity in the 95 cases taken into account in the correlations, the standard deviation (σ) is 4.64. Equation (2) should give for T the closest value possible to compute from all the data on visual acuity. The variations of the actual measurements from this computed value are represented by $\sigma 1.234$, following equation (2), and equal to 4.24. Thus the attempt to express retinal sensitivity in terms of visual acuity is futile. It still deviates in much the same degree from the computed values, and we must conclude that retinal sensitivity, measured by the present method, involves a new characteristic of vision that is not to any significant extent taken into account in the measurement of visual acuity by means of the letter chart.

In examining the relation of the retinal sensitivity results to the ophthalmologic findings as a whole, it was necessary to establish some reasonable means of numerical rating as to the latter. The ophthalmologic examination, of which the results were used, was part of the general medical examination of candidates for flying status, known at the Medical Research Laboratory as "609," from the form number of the blank used to record the results. The criteria

of ophthalmologic qualification, as practiced at the time this work was done, are here reproduced. The method of rating, as will be seen, was to score 1 against the candidate for a contingent disqualification, as implied in the following, paragraphs 3, 5, 8, and 9; to score 2 for disqualification in one particular; and to score 1 for each further point of disqualification. The rules following were interpreted literally. Following each paragraph, in parenthesis, are stated such supplementations and changes as were necessary to make the rating just and unequivocal, or to explain the nature of the test to one unfamiliar with the special practice.

1. *Visual acuity.*—The minimal visional requirement for each eye is 20/20. If two or three letters are not read in the 20/20 line, they may be offset by an equal number of letters read in the 20/15 line.

(The ratings taken in the experimental room were used, not those furnished by the opthalmologist. In view of the qualification in the foregoing paragraph, a subject was passed if he read 20/20 less two letters, assuming in the absence of record of the fact, that he was able to offset these by two read in the 20/15 line. The decimal value 0.92 or over satisfied this condition.)

2. *Depth perception at 6 meters.*—An average depth difference of more than 30 mm. disqualifies the applicant.

(Two rods, 1 cm. in diameter, separated 6 cm. laterally, must not be more than 30 mm. apart in the direction of vision when set to apparent equidistance by the candidate. The rods were seen in silhouette against a bright background, and seen through an opening which did not permit vision of either top or bottom of the rods.)

3. *Maddox rod screen test at 6 meters.*—Esophoria of more than 4△ is a disqualifying factor if associated with less than 4△ of prism divergence, or if associated with diplopia in the lateral positions on the tangent curtain, or if associated with an amount of accommodation near the lower limits, or if associated with an amount of hyperopia near the disqualifying limit.

4. Esophoria of more than 10△ is a disqualifying factor, even if unassociated with any of the preceding conditions.

5. Exophoria of more than 2△ is a disqualifying factor if associated with an angle of convergence near the disqualifying limit, or if associated with diplopia in the lateral positions on the tangent curtain.

6. Exophoria of more than 5△ is a disqualifying factor even if unassociated with any of the preceding conditions.

7. Hyperphoria of more than $\frac{1}{2}$△ disqualifies the applicant without further supporting evidence.

8. *Maddox rod screen test at 33 cm.*—Exophoria of 4△ may be considered the normal condition. Any considerable variation from this condition is to be interpreted in connection with the other associated tests. An exophoria of more than 12△ at 33 cm. disqualifies.

(1 to 7△ exophoria at 33 cm. were taken as the normal condition. Outside of these limits a question was scored.)

9. *Prism divergence.*—Prism divergence of more than 9△ disqualifies the applicant if associated with an angle of convergence near the disqualifying limit. If less than 4△ of prism divergence is found associated with more than 4△ of esophoria at 6 meters, the applicant is disqualified.

(These grades of muscle abnormality which do not disqualify except contingently upon some other finding were marked with a question. One or more questions in the absence of final disqualification scored 1 only against the applicant.)

10. Prism divergence of more than 15△ disqualifies without further supporting evidence. Prism divergence of less than 2△ disqualifies without further evidence.

11. *Test of associated parallel movements.*—The applicant is disqualified if the underaction or overaction of any of the extrinsic ocular muscles causes diplopia except in the extreme positions, where a small separation of the images may be disregarded. Nystagmus disqualifies if it is demonstrated except in extreme positions.

12. *Inspection of the eyes.*—Any pathological condition which may become worse or interfere with the proper functioning of the eyes under the fatigue and exposure of flying disqualifies the applicant.

13. *Accommodation.*—Accommodation is normal if it lies between limits 2 diopters above and below the mean for the applicant's age. Failure to read within these limits disqualifies.

Table of mean values of accommodation power.

Age.	Dptrs.	Age.	Dptrs.	Age.	Dptrs.	Age.	Dptrs.
18	11.9	25	10.2	31	8.6	37	6.8
19	11.7	26	9.9	32	8.3	38	6.5
20	11.5	27	9.6	33	8.0	39	6.2
21	11.2	28	9.4	34	7.7	40	5.9
22	10.9	29	9.2	35	7.3	45	3.7
23	10.6	30	8.9	36	7.1	50	2.0
24	10.4						

14. *Angle of convergence.*—An angle of convergence smaller than 40° disqualifies.

15. *Central color vision.*—If it is apparent that mistakes made by the applicant are due to color confusion and not to carelessness or failure to understand instructions, he is disqualified.

(Color vision was left out of consideration in grading the subjects. There were but three cases not definitely found normal as to central color vision as follows: (1) No record as to color vision, record otherwise incomplete, and subject therefore excluded from consideration; (2) no record as to color vision, disqualified on account of visual acuity and hyperphoria; (3) found to confuse reds and greens. No other disqualification or question.)

16. *Field of vision for form and color.*—The normal visual field for form is largest; those for blue, red, and green are successively smaller in the order given. The color fields should be nearly concentric with the form field. Any marked contraction of the form field disqualifies the applicant for flying.

17. *Refraction.*—The applicant is disqualified if he cannot read 20/20 without more than one diopter of correction, either hyperopic, myopic, or astigmatic.

Concerning paragraphs 11, 12, and 16, it was assumed that no disqualification existed unless specified. The records furnished the writer did not ordinarily state the findings on these points.

Of a total of 101 subjects upon whom retinal sensitivity measurements were made, there were 59 with records complete as indicated above, and only these are included in what follows.

It will be seen from the plot (fig. 3a) that those showing the highest number of points as to opththalmologic defects have, in general a low retinal sensitivity; curve *b* shows the average number of points of defect for each class as to

retinal sensitivity; and curve *d* the average retinal sensitivity for each particular score. Both of these curves bear out the first statement made. The correlation ratio is -0.444 with a probable error of ± 0.070.

If, however, we exclude those having an ophthalmologic score of 4 or more against them, we get a correlation ratio of 0.009 ± 0.094, which is no correlation at all. The curve (*c*, fig. 3b) shows that there is no significant relation between retinal sensitivity and the ophthalmologic findings when those defective with a score of 4 or more are excluded.

We must conclude, therefore, that there is no relation between the defects elicited by the ordinary ophthalmologic examination on the one hand, and the present retinal sensitivity rating on the other; excepting those cases in which the clinical defects are comparatively numerous, in which these are signs of some rather general, perhaps distinctly pathological, derangement of the visual organs which comes to be generally reflected in their various functions, of which retinal sensitivity is one.

This conclusion will perhaps be borne out by inspection of the following synopsis of all results in the 59 cases considered. Where retinal sensitivity was too low to measure this is indicated by the word "low" in place of the numerical result. Otherwise the synopsis should be self-explanatory:

Summary of cases.

Serial No.	Retinal sensitivity.	Clinical description.		Number of cases.
......	....	Unquestioned, score 0		16
......	....	Questioned, score 1:		
......	....	Esophoria	5	
......	....	Exophoria	22	
......	....	High prism divergence	7	
			34	
......	....	Counted twice or more, less	9	
				25
		Just disqualified, score 2:		
101	29.8	Visual acuity	1	
62	17.0	Depth perception	1	
80	28.2	Exophoria at 6 meters	1	
19	19.9	Low convergence	1	
90	28.6	Hyperopia, 1 diopter, esophoria	1	
100	28.7	Hyperopia, 3 diopter	1	
16	18.6	Hyperopic astigmatism, corrected	1	
				7
		Disqualified, score 3:		
42	19.0	Visual acuity and hyperphoria	1	
83	21.7	Hyperopia, low accommodation	1	
91	27.8	Hyperopic astigmatism, low accommodation	1	
				3
		Disqualified, score 4:		
		Hyperopic astigmatism, poor depth perception, with:		
55	15.6	Convergent strabismus	1	
46	Low.	Low visual acuity	1	
82	25.9	Deficient accommodation	1	
				3
		Disqualified, score 5:		
87	31.1	Hyperopia, exophoria, hyperphoria, low convergence and accommodation	1	
85	Low.	Hyperopic astigmatism, low visual acuity and depth perception, hyperphoria	1	
77	Low.	Hyperopic astigmatism, low visual acuity, depth perception and accommodation	1	
				3
		Disqualified, score 6:		
39	17.5	Myopia, corrected: low visual acuity, depth perception and convergence: exophoria		1
		Disqualified, score 8:		
63	Low.	Myopic astigmatism, strabismus, low visual acuity, accommodation and depth perception; impossible to measure convergence		1
		Total number of cases		59

SUMMARY OF CONCLUSIONS.

1. Measurements of retinal sensitivity made upon 101 subjects by a new method, previously described in detail, show individual differences far in excess of the accidental variations for the same individual and the same conditions.

2. The result of any one of as many as four consecutive series is of about equal reliability even with unpracticed subjects.

3. The distribution of the various results of retinal sensitivity measurement suggests a natural division of individuals into two groups, most numerous where the times of stimulation are approximately 27 and 16σ, respectively.

4. Correlation of the results of the first series with those of the second, taken immediately after the first, in 96 subjects, shows almost identical characteristics for the two. The correlation ratio is 0.857 ± 0.018.

5. The characteristic equation derived from correlation of the retinal sensitivity results (average of first and second series) with visual acuity indicate that retinal sensitivity

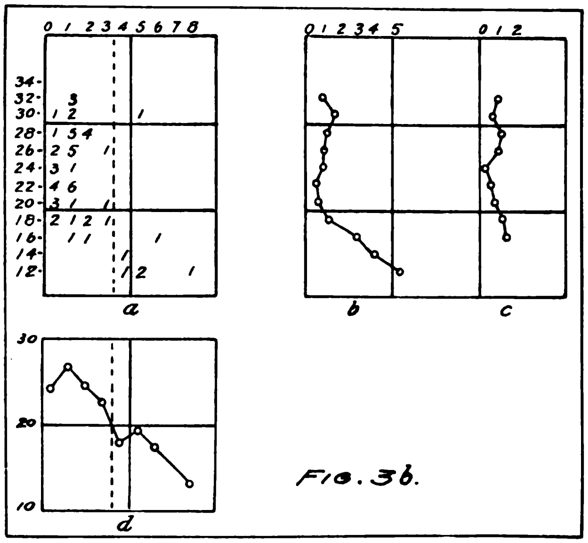


Fig. 3b.

is somewhat dependent upon the visual acuity of the eye with poor vision, but not upon that of the better eye unless the advantage of this latter is evident in enhanced binocular visual acuity.

6. Due allowance for the differences due to different visual acuity leaves individual differences in retinal sensitivity measurements unaccounted for almost to the original amount. The standard deviation from 4.64 is reduced only to 4.24 when correction is made for the differences due to different visual acuity.

7. Correlation between retinal sensitivity and a rating based upon the ophthalmologic portion of the Air Service medical examination for flying status indicate that in general no definite relation exists between retinal sensitivity and disqualification; except when the latter is based on findings which, in degree and character, indicate distinctly pathological conditions.

8. Incidentally, the method of correlation indicates that binocular visual acuity is dependent chiefly upon the eye which, used singly, shows the better vision, to the extent of nearly five times its dependence upon the eye with the poorer vision. This has exclusive reference to results obtained with the letter-chart.

APPENDIX.

The apparatus used in this work differedfrom that used in the former work in the substitution of a perforated and painted metal slip for the punched card formerly used for the test-stimulus aperture. It was found that simply drilling and painting the slip would not suffice, since the paint tended to thin itself, by its surface tension, at the margins of the aperture, causing a ring-shaped shadow by which a photometric balance between screen and aperture was rendered impossible.

The following will give an idea of the technic found necessary in preparing replaceable apertures free from such defect:

Sheet zinc of 0.017-inch thickness was found suitable for the purpose. The hole at the center was drilled to admit the end of a reamer (known to the trade as a "No. 1 taper pin reamer"), provided with a wooden sleeve adjusted so that the hole, reamed from the back until the sleeve just touches the metal, was of just the right size to fit a carefully sized gauge plug. This plug was made for the purpose and measured 0.1687 inch (4.285 mm.) in diameter. The margins of the aperture were then freed from burrs by passing a moderately fine file flat over the front and back surface of the metal.

Before painting the slips, the back of the hole was covered with surgeons' adhesive, and the hole filled with Alabastine (water) paint, mixed to a putty consistency. Beeswax was tried and worked almost as well. The filling was pared down flush with the face of the zinc by means of a clean-edged carpenter's chisel, and the face of the zinc cleaned free of excess filling material at the same time.

The face of the slip was then painted. Two coats of a good ordinary white oil paint were applied in the usual way, and as these nearly covered the metal, a coat of Alabastine white was applied. The filling was then removed by first stripping the adhesive from the back and locating the center of the hole by pricking with a needle, and then carefully punching the filling out from the face piecemeal, without touching the parts which would form the margins of the hole. After this the reamer was run into the hole from the back, as in the first place, carefully and *only* until the collar on the reamer lightly touched the zinc.

The object of this procedure was that the edge of the opening should be perfectly sharp, and that the surface of the face of the slip should continue to be plane accurately and exactly until it met the cylindrical (slightly conical) surface cut by the reamer. If carefully and successfully done, it was readily possible to make the aperture disappear by adjusting the brightness of the back screen. Considerable care had to be used in handling the finished slips, as they were rendered useless by the slightest soiling or chipping of the paint at the margins of the aperture.

EXPLANATION OF TABLES.

Table I.

Measures of fluctuation of the result of a single series for three practiced subjects.

T=Threshold, on arbitrary scale, reduced to standard aperture (area=$10\sqrt{2}$ sq. mm.).

$\sigma(T/_M)$=Standard deviation, relative to the mean for like conditions.

E_T=Probable error, in terms of arbitrary units, as T.

The last three columns give the times corresponding to T, and $T \pm E_T$, respectively.

Table II.

Comparative values and variabilities of the results of four consecutive series: B, C, and L, are three practiced subjects; and the last row gives the results for 33 unpracticed subjects.

N=Number of series concerned in the average.

M=Mean of all values, relative to the mean of all series for the same subject.

MV=Mean variation expressed in the same terms as M. These values, multiplied by 1.253, should be comparable with the values of σ stated in the third column of Table I. The four series consumed an hour's time, more or less, according to the practice and natural aptitude of the subject.

Table III.

The results of correlation of retinal sensitivity (1) with visual acuity (2, 3, 4) measured with the Snellen letters under the conditions of the experiment. The results from the letter chart have been reduced to decimal values (e. g., 20/20=1.00; 20/15=1.33; $20/20+\frac{5}{8}=1.00+\frac{5}{8}\times0.33=1.21$) and the values of σ in division *c* of the table are expressed in such decimal units. Retinal sensitivity is expressed in arbitrary scale units, the same as those in which T is elsewhere expressed.[5]

ss=Subscript indicating the variables involved and their interrelation.

N=number of cases involved.

r=correlation ratio.

σ=standard deviation.

FIGURES, LEGENDS.

(1) Distribution of 192 measurements of retinal sensitivity; the values obtained from the first and second consecutive series of each of 96 different subjects. Abscissæ are (T). Class interval =1. Class types are integral values +0.4. Ordinates are class frequencies.

(*a*) Crosses and solid line frequency by classes.

(*b*) Circles "sliding" averages of four class frequencies.

(*c*) Smooth curve closest fitting normal distribution.

Ten of a possible 202 measurements fail to appear in (*a*) and (*b*) owing to the fact that they were too low to be measures with the apparatus used. These were taken into account in computing the constants of the normal distribution (*c*). See text.

(2) The relation between the results of the first (I) and second (II) series, for each of 96 subjects. The oblique dotted line represents the condition of equality. Those plotted below this line gave a result on the second series lower than that of the first, and vice versa.

(3) The relation between retinal sensitivity measurements and the general degree of visual defectiveness found in the ophthalmologic examination.

(*a*) *Classified results.*—Ordinates indicate class as to retinal sensitivity. The class interval is 2 units on the scale, and the mean of the class is greater than the designation given by 1 unit; e. g., in the 30 class, the lowest possibly included is 30, the highest 31.99, the mean (or type of the class) therefore is 31 minus. Abscissæ points disqualification. See text.

(*b*) Average points of disqualification for each retinal sensitivity class.

(*c*) Same as (*b*), scores of 4 or over excluded.

(*d*) Average retinal sensitivity (ordinate) for each class as to points disqualification. The cases falling to the right of the dotted line in (*a*) and (*d*) are those excluded from (*c*).

—*By courtesy of the Journal of Experimental Psychology.*

[5] For a more complete explanation of the meaning of these symbols and of the methods of correlation see: Yule, An Introduction to the Theory of Statistics, fifth edition, London, 1919; Chap. IX ff, and Chap. XII.

PULSE RATE AND BLOOD PRESSURE RESPONSES OF MEN TO PASSIVE POSTURAL CHANGES. I.

Max M. Ellis, Ph. D., *from the Medical Research Laboratory of the Air Service, Mitchel Field, Long Island, N. Y.*

The development of the airplane has added interest to the circulatory responses of men following passive alterations of body position, for the aviator is subjected frequently to sudden variations in body position, which are largely passive as far as his musculature is concerned. Changes in pulse rate and blood pressure correlated with changes in body position made by the subject have been studied by many investigators, but the changes in circulation accompanying postural changes in which the subject is moved by some force outside of his body have not received the same attention.

In experiments on animals Hill (1895) showed that the blood pressure in the carotid artery was increased by tilting the animal from the horizontal to the head down position and decreased by tilting from the horizontal to the head up position. Barach and Marks (1913), working with young men 15 to 30 years of age, on a tilting table, concluded that "when the element of muscular effort has been eliminated, change of body posture from the erect to the horizontal will cause an increase in the maximum pressure, a decrease in the minimum pressure, and an increase in the pulse pressure." Henderson and Haggard (1918) followed the circulatory responses in the head down position of 10 young men on the tilting board, and report that "in the inverted or head down position (30 to 45°) the heart rate in 10 men was slower than in the flat position by an average of 9.5 beats a minute and slower than the erect position by 17."

Excepting two cases (in the tilt from the erect to the reclining position) all of the pulse responses were minus in the tilts which lowered the head and plus in those which raised the head. The responses in systolic and diastolic pressures were not so uniform. The systolic pressure of 5 of the 10 men and the diastolic pressures of all 10 fell on changing from the erect to the horizontal. On tilting from the horizontal to the head down position the systolic pressure rose in some cases and fell in others, the subjects being about equally divided between the two responses. The same was true of the responses to the return tilt; i. e., from the head down position to the horizontal. The diastolic responses following both of these tilts were also about equally divided between plus and minus. Although the work of Stephens (1904) is not strictly comparable with the preceeding articles because his subjects were not tilted except from the reclining to the head down position, his averages of the responses in pulse rate, and systolic pressure to changes in body position are interesting in this connection. These averages show a decrease in the per minute heart rate and an increase in the systolic blood pressure from the erect position, through the sitting and reclining positions to the head down position. Stephen's data were collected after the circulatory balance was reached by his subjects. More recently Barach (1919) summarizes the responses in pulse rate, systolic and diastolic pressure of 48 normal adults to two passive tilts. When these subjects were tilted from the standing position to the reclining he found that the pulse rate and diastolic pressure fell and the systolic pressure rose. Following the return tilt from reclining to standing position the pulse rate and diastolic pressure rose and the systolic pressure fell.

These observations collectively suggest that the circulatory responses of men to passive tilts which lower the head are a decrease in the per minute pulse rate, an increase in the systolic pressure (sometimes a decrease) and a decrease in the diastolic pressure (sometimes an increase).

The present study was undertaken at the Medical Research Laboratory of the Air Service with a view to obtaining additional data on the constancy of these responses of men to passive postural changes of various sorts and on the degree of these responses.

Fifty young men, 20 to 31 years of age, drawn from the Medical Department and from the Air Service of the Army, were used as subjects. Each man was given the routine physical examination by an internist and by an ear, nose, and throat specialist before selection for these tilt tests. No man not reported sound was taken. All of the subjects were familiarized with the tilting table and its operation before the tests were made, to eliminate the factor of surprise. During the tests the subject refrained from talking and the observers spoke only when necessary.

The tilting tests were made by two observers, one taking the pulse counts and the other the blood pressures throughout the test. The subject was placed on the tilting table and swung up into the horizontal plane, here termed the "reclining position," after the blood-pressure apparatus was attached to the left arm (a Tycos apparatus was used and the readings taken by auscultation) the subject was undisturbed 10 minutes, when the first records of pulse and blood pressure were taken simultaneously. Three readings were made and the averages taken as the normals against which the subsequent readings in other positions were checked. As soon as the normals were established the subject was tilted quickly and quietly into the new position and a new reading taken. As assistants were always present to look after the mechanical side of the tilting, the observers were able to make the first count of pulse rate and the first measurements of

blood pressure within 30 seconds after the tilt. These figures have been recorded in the tables as the "immediate response." After the immediate response was recorded the subject was again undisturbed for five minutes. At the end of five minutes a second set of records was taken which has been termed the "response at the end of the fifth minute." These readings completed, the subject was tilted to the next position and the process repeated. Effort was made to take all readings at the end of expiration, but this was not always possible. From these several sets of readings, the amount and direction of change in the pulse rate and blood pressures during the first 30 seconds after the body position was altered, the amount and direction of change at the end of the fifth minute, and the amount and direction of change during the five minutes in each position were obtained. In establishing these values the readings in a given position were compared with those taken at the end of the fifth minute in the preceding position. Five-minute intervals were chosen because it was found by preliminary tests in which minute to minute readings were taken that the subjects generally reached their maximum responses and adjustments to the new position within the first three minutes after the tilt was made.

Two series of tilts were used. In the first series the subject was tilted from the reclining position to head up 45°, head up 45° to standing, standing to reclining, reclining to standing, standing to head down 45°, head down 45° to standing. In the second series the first three changes of position were identical with the first three of the first series, i. e., from reclining through head up 45° and standing to reclining again. Then followed tilts from reclining to head down 45° and head down 45° to reclining. (See Fig. 1c.)

GENERAL RESPONSES.

Considering the responses in pulse rate, systolic pressure, and diastolic pressure separately, correlated only with the changes in the position of the subjects, the responses in pulse rate were the most uniform of the three. Ninety per cent of all cases in which the head was elevated during the tilt showed an immediate rise in pulse rate, and 84 per cent had a higher pulse rate at the end of the fifth minute after a tilt which elevated the head than at the end of the fifth minute in the previous position. The opposite tilts, those in which the head was lowered, gave much the same grouping of cases, with the opposite pulse response. Ninety-one per cent showed an immediate fall in pulse rate on lowering the head, and 86 per cent had a lower pulse rate at the end of the fifth minute than in the previous position. The predominate pulse responses, therefore, to all changes of position taken collectively were (1) an increase in pulse rate—plus response—on raising the head, and (2) a decrease in pulse rate—minus response—on lowering the head. All of the several types of tilts produced these responses, as from 62 to 100 per cent of the cases in each tilt gave the responses designated above as the predominate responses. In the main these predominate responses were supported by larger percentages immediately after the tilt was made than at the end of the fifth minute, suggesting that the pulse response was compensatory to the sudden change in position of a considerable volume of blood by gravity, and that additional responses during the next five minutes completed the adjustments to the new body position. This is confirmed by the changes in blood pressure during the five-minute interval. In some of the tilts these readjustments amounted to a change in the character of the blood-pres-

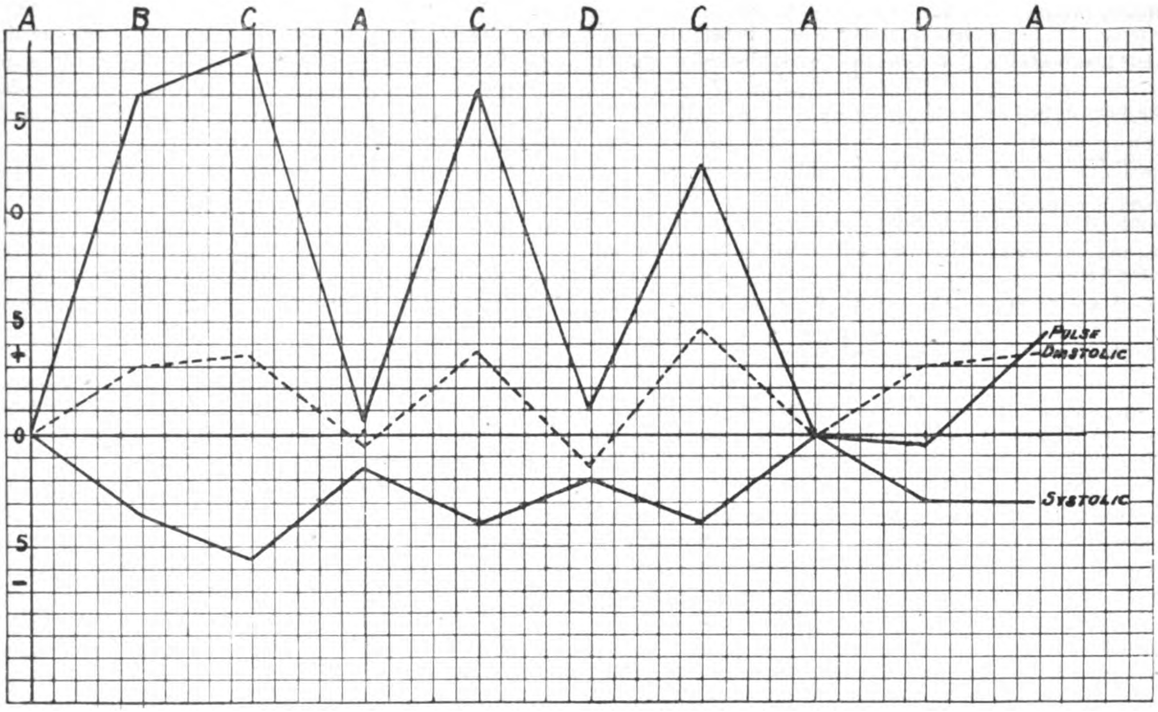


FIG. 1c.—Average deviations in pulse rate, systolic pressure, and diastolic pressure from the reclining normals at the end of the fifth minute after each tilt. Tilts plotted in sequence used in the tests. Pulse rate plotted in beats per minute and blood pressures in millimeters of mercury. A, reclining; B, head up 45°; C, standing; D, head down 45°.

sure response from minus to plus. Although in other tilts this shifting of blood pressure was not so profound, in all tilts excepting that from head down to standing more of the subjects showed a zero blood-pressure response at the end of the fifth minute than immediately after the change of position (Table 1).

TABLE 1.—*Responses to tilts.*

Tilt.	Cases.	Pulse.			Systolic.			Diastolic.		
		Rose.	Held.	Fell.	Rose.	Held.	Fell.	Rose.	Held.	Fell.
All tilts raising head..	244	*90*	5	5	17	9	*74*	*58*	7	35
		84	5	11	21	21	*58*	*60*	20	20
All tilts lowering head.	108	8	1	*91*	*48*	9	43	18	8	*74*
		6	8	*83*	*48*	13	39	24	9	*67*
Head down to reclining.	46	*79*	4	17	38	22	38	34	22	*44*
		69	14	17	38	18	*44*	*47*	23	30
Head down to standing.	32	*100*	0	0	33	0	*67*	*67*	0	33
		100	0	0	17	17	*67*	*83*	0	17
Reclining to head up 45°.	58	*100*	0	0	4	4	*92*	*82*	4	14
		100	0	0	18	14	*68*	*76*	10	14
Reclining to standing..	50	*100*	0	0	12	8	*80*	*68*	4	28
		100	0	0	20	24	*66*	*68*	24	8
Head up 45° to standing.	58	*79*	17	4	14	7	*79*	41	4	*55*
		62	7	31	18	27	*55*	*41*	24	35
Reclining to head down 45°.	34	17	0	*83*	12	12	*76*	35	12	*52*
		12	17	*71*	24	12	*64*	*59*	17	24
Standing to reclining..	42	5	0	*95*	*76*	0	24	14	5	*81*
		5	5	*90*	*71*	5	29	19	5	*76*
Standing to head down 45°.	32	0	6	*94*	*50*	19	31	19	0	*81*
		0	0	*100*	*50*	25	25	19	6	*75*

Data given in per cents for direct comparison. First line in each pair gives the immediate response as compared with the normal in the previous position; the second line gives the response at the end of the fifth minute after the tilt.

The blood-pressure responses were not so sharply grouped as were the pulse rate changes. The predominate responses in general, as indicated by the highest percentages, were a fall in systolic pressure and a rise in diastolic pressure following those tilts which raised the head, and a rise in the systolic pressure and a fall in the diastolic pressure following those tilts which lowered the head. The diastolic pressure varied in the same direction as the pulse rate and the systolic pressure in the opposite direction. The predominate blood-pressure responses were supported by much smaller percentages than were the changes in pulse rate. In several of the tilts the cases were about equally divided between plus and minus blood-pressure responses, indicating that the blood-pressure responses were much less constant than the pulse rate changes.

Three separate tilts did not follow the predominate responses of blood pressure as determined by the mass data of all classes. In the reclining to head down tilt the systolic responses of 76 per cent of the cases were minus immediately after the tilt, and 64 per cent held a systolic pressure lower than the reclining normal to the end of the fifth minute. The diastolic pressures of 52 per cent also fell below the reclining value immediately after the tilt (the response expected from the predominate responses of the mass data of head lowered tilts), but in 59 per cent of the cases of this tilt the diastolic pressure rose during the five-minute interval above the reclining normal. In the reclining to head down tilt, therefore, the pulse response followed the typical response of all head down tilts, the systolic pressure fell instead of rising and the diastolic pressure fell as expected immediately after the tilt but rose above the reclining valne during the next five minutes.

The other two exceptions to the predominate responses of the mass data were in the diastolic pressure responses. In both the head down to reclining and head up 45° to standing tilts, the immediate diastolic response was a fall in pressure below the former value, followed by a rise during the next five minutes. The diastolic exceptions in all three tilts, therefore, were all of one type, an initial fall regardless of the position from which the tilt was made, followed by a rise above the value in the preceding position during the next five minutes. It is to be noted also in this connection that in each of the three tilts in which the diastolic pressure did not follow the predominate response of the mass data, the cases of each tilt were about evenly divided between plus and minus response. As is shown under the discussion of the degree of change, in these three tilts the actual amount of change in pressure measured in millimeters of mercury was slight and the diastolic pressures in these three tilts may represent indifferent responses.

If the predominate responses in pulse rate, systolic pressure, and diastolic pressure, as determined in Table 1 by the largest percentage of cases in each tilt group, be summarized in a formula (P=pulse, S=systolic pressure, D=diastolic pressure), P+S−D+ represents the predominate responses of the largest per cent of cases to a passive tilt in which the head was raised, regardless of the initial position from which the tilt was made. Similarly, P−S+D− represents the predominate responses of cases in which the head was lowered, excepting the tilt from reclining to head down. In this tilt the largest per cent of cases gave the P−S−D+ responses.

These three formulæ of responses from the mass data were applied to the actual records of each individual case to determine the degree of correlation existing between the three responses of pulse rate, systolic, and diastolic pressures. The responses at the end of the fifth minute after the tilt were used (Table 2). Only one-third of all cases in which the head was elevated during the tilt gave the expected responses in all three variables, pulse rate, systolic and diastolic pressures. In the tilts lowering the head the percentage was slightly higher but still below 50 per cent. In only two tilts did the percentages of cases agreeing with the formula of responses exceed 50 per cent in the head down to standing tilt and in the reclining to head up 45° tilt. Cases giving any two of the predicated responses were more numerous, including 50 per cent or more of the subjects in each tilt with the exception of the head down to reclining tilt. A comparison of the cases giving any two of the expected responses suggests that there is little difference in the constancy of the systolic and diastolic blood pressures, as the PS and PD groups were about the same. Fewer subjects gave both of the predicted blood-pressure responses than gave the predicted pulse and either one of the blood-pressure responses. This was excepted from the summary of the mass data (Table 1) as the pulse rate changes were the most constant of the three responses. This confirmation of the grouping in Table 1 gives added value to those percentages, which show not only the relative constancy of each response but also that the predominate method of compensation was a change in pulse rate.

TABLE 2.—*Correlations of the three responses, pulse rate (P), systolic pressure (S), and diastolic pressure (D).*

[Data in per cent of cases giving responses indicated.]

Tilt.	P+S−D+.	P+S−.	P+D+.	S−D+.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
Head down to reclining	13	30	39	26
Head down to standing	67	67	83	67
Reclining to head up 45°	55	72	70	55
Reclining to standing	32	50	56	32
Head up 45° to standing	21	48	27	30
All head-up cases	33	52	·50	38
	P−S+D−.	P−S+.	P−D−.	S+D−.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
Standing to head down	31	50	70	31
Standing to reclining	38	57	62	43
	P−S−D+.	P−S−.	P−D+	S−D+.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
Reclining to head down	47	58	53	47

It is evident from Table 2 that the responses to changes in position were not equal in the three variables, pulse rate, systolic pressure, and diastolic pressure, and that there was no stereotyped response which included the majority of cases. Satisfactory compensations, at least such as would maintain the individual for five minutes without loss of consciousness (none of the subjects fainted during the tilts), were made by other combinations of pulse, systolic and diastolic responses than those expected from the mass data.

DEGREE OF RESPONSE.

In Figure 1 the mean values of change in pulse rate per minute and blood pressure in millimeters of mercury have been plotted, taking the several tilts in the sequence in which they were made on the subject. The mean values were obtained after the actual values of all individual cases had been plotted by classes. As the pulse-rate counts were made in 20-second units and multiplied by 3, a deviation of plus or minus one count by the observer has been allowed, and similarly a deviation of plus or minus one unit (2 millimeters) on the Tycos dial has been allowed in the blood-pressure readings. The zero class of the pulse values included, therefore, all cases whose responses varied from plus three beats to minus three beats per minute and the zero classes in the blood pressures all from minus 2 millimeters to plus 2 millimeters. The class ranges for pulse rates were nine beats per minute and for blood pressure 6 millimeters of mercury.

The tilts from reclining to head up 45° and from reclining to standing gave almost identical degree changes, being P+16 beats, S−3.5 millimeters, D+3 millimeters, and P+16, S−4, D+3.5 respectively at the end of the fifth minute after the tilt. When the standing position was reached by two tilts, i. e., reclining to head up 45° and head up 45° to standing, greater deviation from the reclining normals of pulse rate, systolic and diastolic pressures were obtained, the responses at the end of the fifth minute of standing after these two tilts being, P+18, S−5.5, D+3.5. These values equal or exceed each of the three responses to either the reclining to head up 45° tilt, or the reclining to standing tilt. When the standing position was reached by one tilt from the head-down position, i. e., the head-down to standing tilt the pulse response was smaller and the diastolic response greater than either of the other two standing values. The response at the end of the fifth minute of standing after the head-down to standing tilt were P+12, S−2, D+6, and the deviations from the reclining normals P+13, S−4, D+4.5.

In the reverse tilts, standing to reclining, opposite responses obtained, P−17.5, S+4, D−4, so that the readings at the end of the fifth minute in the reclining position were almost identical with the normals taken in the reclining position. In the standing to head-down tilt the response in pulse was not as great as in the standing to reclining tilt, being P−15, S+2, D−5. Although less than the responses from standing to reclining, these values following the standing to head-down tilt are fairly close reverse responses to those following the head-down to standing tilt. The responses after that tilt were P+12, S−4, D+4.5. It is evident that a subject does not relax as completely in the unusual position of head down 45° as in the reclining position, and the factor of muscular effort, either conscious or unconscious, is not completely eliminated in the head-down position. Similarly a certain amount of muscular effort on the part of the subject can not be avoided in the standing position even though the subject is brought to this position by forces outside of his body. In the head-down to standing tilt, therefore, the muscular effort of the subject and the movement of the blood by gravity both contributed to the reactions of the subject.

In order to ascertain the responses to the head-down position following a tilt from a position in which the muscular effort of the subject was eliminated as far as possible, part of the subjects were tilted from the reclining to the head-down position and then back to the reclining position. The responses at the end of the fifth minute in the head-down position following the reclining to head-down tilt were quite different from those at the end of the fifth minute in the head-down position following the standing to head-down tilt. Following the reclining to head-down tilt the deviations from the reclining normals were P−0.5, S−4, D+3 at the end of the fifth minute as compared with P+1, S−2.5, D−1.5 at the end of the fifth minute after the standing to head-down tilt. After the return tilt, head down to reclining, the subjects did not return to the reclining normals in five minutes, the average deviations from the reclining normals being P+4, S−2,5, D+3.5.

From these various degree values it seems that the subjects examined made rather complete adjustments in five minutes to tilts in the reclining-standing quadrant, as the changes in pulse and blood pressure in one direction are offset by approximately equal changes in the opposite direction on reversing the tilt. In the reclining to head-down quadrant the responses were much less uniform, and the circulatory balance was probably not established in the five-minute interval. Tilts starting in the reclining-standing quadrant and ending in the reclining head-down quadrant, or vice versa, gave more uniform and also more profound responses than tilts in the reclining head-down quadrant alone. These tilts, however, which carried the

subject through more than 90°, showed the disturbing effect of the head-down position, either at the beginning or the end of the tilt, upon the general compensations of the body to changes in position.

Considering the mass data of all cases collectively the responses obtained from these 50 men were in general the responses expected from the review of previous experimentation. The formulæ P+S−D+ for the tilts raising the head and P−S+D− for those lowering the head, included the largest percentages of responses in all tilts excepting the reclining to head down tilt, the mass responses of which were P−S−D+. The application of these formulæ, however, to the individual cases showed that a relatively low per cent of the individuals actually gave three responses simultaneously and that these formulæ were therefore unreliable for the study of individual subjects even among men who had been pronounced in good physical condition. The response to passive changes in body position as evidenced by the data here offered, was primarily one of change in pulse rate. The blood pressure responses were much more subject to individual variation in the general adjustment following these passive body position changes, although the blood pressure responses did show definite groupings in the mass data. As the effect of the shifting suddenly of a quantity of blood by gravity could produce through its effect on the nervous mechanism controlling the heart, changes in pulse rate such as followed the changes in body position, and as several other factors are involved in the blood pressure changes, a greater constancy of the pulse responses might be expected.

The responses in systolic pressure to the reclining to standing tilt were so different from those given by Crampton (1913) for healthy men on standing from the reclining position that the mass data may be reviewed here for comparison. Crampton states "that in the perfectly normal there occurs upon rising from the recumbent position a vasoconstriction effort which squeezes these veins (splanchnic) and raises the blood pressure, which more than overcomes the hydrostatic load." In the tilt from reclining to standing the mass response was a fall in systolic pressure, supported by 80 per cent of the cases immediately after the tilt, and by 66 per cent at the end of the fifth minute, instead of the rise in systolic pressure found by Crampton in the men who stood voluntarily. As the subjects used in these tilting tests had been reported sound by the examining surgeons the vasomotor tone of the subjects was presumably good. The fall in systolic pressure following the tilting of these men from reclining to standing suggests either a lag in this compensatory vasoconstriction effort or a greater demand for compensation than could be met by the splanchnic area alone. As the per cent of cases giving the fall in systolic pressure fell during the five-minute interval from 80 to 66 per cent there was some compensation which raised the blood pressure during the five-minute period in at least 14 per cent of the cases. In the case of the individuals rising by their own muscular efforts the tightening of various muscles of the body which would occur in the act of rising, would in part prevent the fall in pressure which took place in the reclining subjects who were suddenly tilted into the standing position. The relative demand, therefore, for compensation from the splanochnic vessels would be greater in the case of the tilted subjects than in that of the subjects rising by their own muscular effort.

SUMMARY.

1. In general tilts elevating the head gave a rise in pulse rate, a fall in systolic pressure and a rise in diastolic pressure, and those lowering the head a fall in pulse rate, a rise in systolic pressure, and a fall in diastolic pressure. The conspicuous exception to these responses was the reclining to head down tilt in which the largest per cent of cases gave a fall in pulse rate, a fall in systolic pressure, and a rise in diastolic pressure.
2. The individual data showed that only a little over one-third of all cases gave the three responses in pulse rate, systolic and diastolic pressures expected from the mass date, simultaneously.
3. Tilts from reclining to head down 45 degrees and return gave the least constant responses of all the tilts used.
4. The tilt from reclining to head up 45 degrees produced almost the same degree of responses as the tilt from reclining to standing.
5. With the exception of the tilts in the head down to reclining quadrant the responses given to any tilt were offset by approximately equal opposite responses when the tilt was reversed.
6. The initial and final positions of the subject had more effect on the degree of responses following a tilt than did the distance travelled by the subject during the tilt.

The writer wishes to acknowledge his obligations to Lieut. Harry Fried, M. C., who assisted in a large number of these tilting tests.

BIBLIOGRAPHY.

Barach: Arch. Int. Med., xxiv, 509, 1919.
Barach and Marks; Arch. Int. Med., xi, 485, 1913.
Crampton: N. Y. Med. Journ., Nov., 1913.
Henderson and Haggard; Journ. Pharm. Exp. Ther., xi, 189, 1918.
Hill; Journ. Physiol., xviii, 15, 1895.
Stephens; Journ. A. M. A., xliii, 955, 1904.

By courtesy of the American Journal of the Medical Sciences.

PULSE RATE AND BLOOD PRESSURE RESPONSES OF MEN TO PASSIVE POSTURAL CHANGES. II. UNDER LOW OXYGEN.

MAX M. ELLIS, Ph. D., *formerly of the Department of Physiology, Medical Research Laboratory.*

Fifteen men from the Air Service and the Medical Corps of the United States Army were used as subjects in these tests. The changes in position were made by means of a tilting table and with little or no muscular effort on the part of the subject. The pulse rate and blood pressures taken after 10 minutes reclining constituted the normals on which the comparisons were based. Low oxygen conditions were obtained in two ways, by rebreathing and in the low-pressure chamber.

The data collected showed:

1. The responses under low oxygen were of the same type as those made by the subject at sea level, until the lack of oxygen became so severe that collapse was imminent.

2. The actual amount of change in pulse rate and blood pressure varied slightly from the sea-level responses until 10,000 feet equivalent altitude was exceeded.

3. Above 10,000 feet equivalent altitude the responses were more profound than those at sea level, the differences in pulse rate being the most noticeable. These responses increased as the equivalent altitude was increased.

4. Just before collapse from low oxygen the passive changes in position failed to bring about large changes in pulse and blood pressure, the tendency being for all three, i. e., pulse, systolic and diastolic pressures, to fall when the subject was tilted.

—By courtesy of the American Journal of Physiology.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV August 1, 1922 No. 360

REPORT OF STATIC TEST OF THE JUNKER L-6 MONOPLANE

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by
E. R. Weaver
Engineering Division, Air Service
McCook Field, Dayton, Ohio
November 8, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT OF STATIC TEST OF THE JUNKER L-6 MONOPLANE.

SUMMARY OF RESULTS.

Airplane: Junker, A. S. No. 64121.
Type: L-6.
Total weight: 3,910 pounds.
Wing area: 385.6 square feet.
Engine: 6-cylinder 185 horsepower B. M. W.

Description: All-metal monoplane, capable of carrying four passengers with baggage and two pilots; has dual control arranged side by side. The JL-6 airplane compares favorably in weight and performance with the U. S. A. Type XI. All tests were based on the requirements of this type.

Date.	Part tested.	Results of test.				
		Supported factor of—	Failed at—	Factor required.	Unit weight (pounds per square foot).	Failure.
1921.						
Apr. 22	Horizontal stabilizer	6.5		5	1.17	Stabilizer and elevator did not fail.
Do	Elevator	5		5	.77	
Do	Elevator control	3	4	5		Bulkhead-supporting elevator-control walking beam failed.
Apr. 25	Vertical fin	5		4	.94	
Do	Rudder	5		4	.82	
Do	Rudder control	5	5.5	4		Left rudder-control pedal of right control failed by twisting.
	Ailerons					Ailerons and aileron controls could not be tested on account of damaged wing.
	Aileron controls					
	Wing cellule:					
June 1	High incidence	6	6.5	5.5	1.27	Both wing spars and wing spar ball joints failed.
May 27	Low incidence	3.5		3.5	1.27	
June 6	Fuselage	6.5	7.0	5.0		Engine supports collapsed and fuselage body buckled.

DISCUSSION.

The JL-6 monoplane developed sufficient strength throughout the various tests, with the exception of the control system, which is very weak. Considerable lost motion in the controls was noticed. This is due to the number of clevis pins used in the control system. Otherwise, the fuselage and surfaces are structurally satisfactory.

OBJECT.

This static test was conducted for the purpose of determining the structural strength of the JL-6 monoplane.

DATE AND PLACE.

The various component parts of the airplane were all tested at McCook Field, Dayton, Ohio, on the dates indicated below:

April 22, 1921.—Elevator and stabilizer.
April 25, 1921.—Rudder and fin.
May 27, 1921.—Wing cellule (low incidence).
June 1, 1921.—Wing cellule (high incidence).
June 6, 1921.—Fuselage.

WITNESSES (ALL TESTS).

Lieut. C. N. Monteith. Lieut. C. W. Pyle.
Lieut. E. W. Dichman. Mr. W. E. Savage.
Mr. D. B. Weaver.

SUMMARY.

The entire airplane, with the exception of the controls, developed sufficient strength in the test. Structurally the airplane is strong enough. It is a remarkable example of all-metal construction.

GENERAL RECOMMENDATIONS.

Since the control stick torque tube failed in bending at an average loading of 20 pounds per square foot, it is recommended that this tube be shortened or reinforced.

In fact, the whole control system is bad, and a complete new control system should be designed for this airplane.

GENERAL DESCRIPTION.

The JL-6 is an all-metal monoplane, the whole structure being built up of duralumin tubes, channels, angles, and corrugated sheets. The wing covering ranges from 0.012 at the tip to 0.021 inch in thickness at the root. The fuselage covering is 0.012 inch in thickness.

The whole structure is riveted together. The airplane has dual control, and the two pilots are seated side by side in the pilot's cockpit just ahead of the cabin. The cabin is arranged to accommodate four passengers comfortably, or, in other words, the airplane will carry 960 pounds of passengers and pilots.

The engine is a 6-cylinder B.M.W. of 185 horsepower.

Figures 1 and 2 are three-view drawings, showing the general design.

WING CELLULE.

DESCRIPTION.

The wing cellule is entirely of duralumin, with the exception of spar fittings and the fittings at the large ends of the spars where the ball joints are attached. These fittings are all steel.

The wing spars are tubular, each spar being built up of three different sizes of tubing telescoped at the joints, which are riveted. Figure 15 is a drawing of one spar showing the joints and the size of the tubing used. The only difference in the spars is the slight difference in length.

Figure 16 is a drawing of ball joint used in coupling the wing spars to the spars of the center section.

The internal wing bracing is of corrugated duralumin. These brace members are placed diagonally, the heavy members being used nearest the fuselage and the lighter members are used in the outer portion of the wing. All the brace members are corrugated except the bracing members of the center section, which are tubular, being reinforced on the inside and flattened at the end and riveted to the spar fittings.

Figures 11 and 12 show the method of bracing. Figure 13 shows the cross section of the corrugated braces used. Figure 54 is a photograph of the wing with half the wing cover removed.

The junker wing has nine major spars and one short tubular spar nearest the trailing edge, which is merely a stiffening member for the trailing edge.

The top and bottom wing covers are riveted together at the trailing and leading edges. A reinforcing strip is used at the leading edge, but none is used at the trailing edge.

Figure 14 shows the wing section at the junctions of the wing and the center section. Figure 9 is a wing diagram showing lateral load divisions. Figures 17 and 18 are aileron drawings showing aileron layout and sections.

No test was made of the aileron, due to the fact that the left wing was damaged to such an extent that it could only be used as a counterbalance in testing the right wing.

Figure 19 is a table of thicknesses of wing covering. Figure 20 is a table of weights and areas.

NOTE.—No reverse flight test was necessary.

PROCEDURE OF TEST (LOW INCIDENCE).

The wings were attached to the fuselage as for flight; the airplane inverted and loaded in accordance with the loading schedule in Figure 3.

The angle of inclination of the wing chord to the horizontal (angle γ) was 9° 32′ trailing edge down and was determined from the high-speed angle of incidence α and the angle β between the lift and the resultant air force.

$$\alpha = -3° 20'.$$
$$\beta = +6° 12'.$$
$$\gamma = \beta - \alpha = 6° 12' - (-3° 20').$$
$$= 9° 32'.$$

The center of gravity of the load was located at 60 per cent of the chord from the leading edge, which corresponds to the position of the center of pressure of the JL-6 wing at $\alpha = -3° 20'$.

RESULTS.

Since the JL-6 tested had a damaged left wing which was repaired by wood members so as to serve as a counterbalance in the test, the results obtained are for the right wing alone.

The wing supported a load equivalent to a factor of 3.5 with no failures.

The deflections and retreat are tabulated in Figure 4 for spars Nos. 5 and 3. Figure 5 shows the deflection curves for the low incidence. Figure 56 is a picture of the low-incidence setting with a part of the load on.

PROCEDURE OF TEST (HIGH INCIDENCE).

After the low-incidence test had been completed, the airplane was reset in the inverted position for the high-incidence test. The wings were then loaded in accordance with the loading schedule in Figure 6.

The angle of inclination of the wing chord with the horizontal (γ) was 9° with the leading edge down, and was determined from the low-speed angle of incidence α and the angle β between the lift and the resultant air force.

$$\alpha = 16°.$$
$$\beta = \cot^{-1} L/D = \cot^{-1} 8.2 = 6° 57' \text{ (say, } 7°).$$
$$\gamma = \alpha - \beta = 16° - 7° = 9°.$$

The center of gravity of the load was located at 35 per cent of the chord from the leading edge, which corresponds to the position of the center of pressure of the JL-6 wing at $\alpha = +16°$.

RESULTS.

The deflections are tabulated in Figure 7. Figure 8 is a chart with curves representing the deflections of spars Nos. 4 and 2 at the various load factors. The wings were loaded to a factor of 6.5 when failure occurred.

The right wing broke off at the junction of the wing and the center section.

On examining the failure it was noted that on spars Nos. 1 and 9 the threads sheared off of the couplings.

On spars Nos. 8 and 10 the failure occurred in the center section where the tubes failed in tension.

Spar No. 7 failed in tension on the wing side of the joint.

Six of the corrugated brace members of the wing spars failed by buckling.

No wrinkling of the wing covering was noticed as the material was corrugated.

Figures 60 and 61 are pictures of the failures of the spars and joints. Figure 10 is a diagram of the spar failures.

DISCUSSION.

Subsequent examination of the failures showed that the shearing strength of the threads on the spar ball joints was equivalent to the tensile strength of the duralumin spar.

Figures 57 and 58 are pictures of the high incidence set up with the load on.

Since the left-wing load had been repaired and could be used only as a counterbalance, the load was not put on this wing in the same manner as on the wing being tested. The same loading was applied to both sides,

however, but on the repaired wing it was piled higher and along the center of the wing, which makes it appear in the picture (fig. 57) to be loaded heavier on this wing than on the other.

CONCLUSION.

The wing cell developed sufficient strength in the static test and proved to be an excellent example of all-metal construction.

STABILIZER AND ELEVATOR.

DESCRIPTION.

The stabilizer and elevator are of all-metal construction, duralumin being the material. The stabilizer is nonadjustable and the elevators are unbalanced.

Both of the elevators are built on the same spar and operated simultaneously by a mast projecting inside the fuselage and attached to the tube which forms the main spar.

Figure 22 is the stabilizer assembly showing sections.

Figures 23, 24, 25, and 26 are stabilizer detail construction drawings showing sections. Figure 27 is the elevator assembly. Figure 28 is a drawing of the details of construction of the elevator.

The total area of the stabilizer is 28 square feet, while the weight is 33 pounds, or 1.17 pounds per square foot.

The total area of the elevator is 20.8 square feet and the weight is 16 pounds, or 0.77 pound per square foot.

PROCEDURE.

The stabilizer and elevator were mounted on the fuselage as for flight. The surfaces were then loaded according to the loading schedule in Figure 21.

A spring balance was coupled in the controls to register the pull in the controls.

The deflections were taken after each additional increment of the load has been in place for a period of five minutes.

The center of gravity of the load on the elevator is located at five-twelfths of the mean chord from the hinge pin center.

RESULTS.

At an average loading of 15 pounds per square foot the control stick was seen to bend. The pull on the stick (as indicated by the spring balance) was 150 pounds.

At an average loading of 20 pounds per square foot the control stick torque tube failed in bending. This tube is the transverse tube on which both the control sticks are mounted, the JL-6 having a dual control with pilots seated side by side.

The front part of the controls were disconnected and the test continued.

At an average loading of 25 pounds per square foot the bulkhead supporting the walking beam between the first and second linkages of the elevator control failed. Both the rivets tore out and the metal tore where the failure occurred.

Figure 35 shows a sketch of the rear part of the elevator controls, which shows the forces in the control members and also the force exerted on the bulkhead which caused the failure.

A table of deflections and a loading schedule may be found in Figure 21.

The stabilizer held a loading of 32.5 pounds per square foot without failure. The test was then discontinued.

Figure 65 is a picture of the fuselage showing the elevator controls. Figure 64 is a picture of the failure of the bulkhead. Figure 34 is a drawing of the aileron and elevator control.

DISCUSSION.

The required average load per square foot for the horizontal tail surfaces is 25 pounds for an airplane of this type. Since the surfaces themselves showed no signs of failure during the test, they are structurally satisfactory. However, the controls are weak, since the failure of the control stick occurred at an average loading of 15 pounds per square foot and the failure of the torque tube occurred at an average loading of 20 pounds per square foot. The bulkhead failed at an average loading of 25 pounds per square foot.

RECOMMENDATIONS.

The control stick torque tube should be heavier or else have more support near the center of the tube.

A piece of corrugated duralumin riveted in the fuselage between the fuselage cover and the bulkhead mounting the elevator-control walking beam would strengthen the bulkhead sufficiently.

RUDDER AND FIN.

DESCRIPTION.

The rudder and fin are of all-metal construction, duralumin being used throughout.

Both rudder and fin are covered with duralumin of 0.012 inch in thickness.

The rudder is unbalanced. The weight of the rudder is 9.5 pounds. The weight of the fin is 5 pounds. The area of the rudder is 11.5 square feet. The area of the fin is 5.3 square feet. The weight per square foot of the rudder is 0.826 pound. The weight per square foot of the fin is 0.943 pound.

PROCEDURE.

The rudder and fin were mounted on the fuselage as for flight. The fuselage was then turned on its side and the surfaces loaded according to the loading schedule in Figure 29.

A spring balance was coupled in the controls to register the pull in the members.

Deflections were taken after each additional increment of the load had been in place for 5 minutes.

RESULTS.

The rudder and fin carried the load satisfactorily all through the test, but the left rudder pedal of the right control failed by twisting at an average loading of 27.5 pounds per square foot.

The test showed that the vertical tail surfaces were well constructed.

The results are tabulated in Figure 29. Figure 30 is a drawing of the rudder showing sections. Figure 31 shows detail drawings of the rudder. Figure 32 is a drawing of the fin showing sections. Figure 33 is a drawing of the rudder-control pedals.

DISCUSSION.

Since an average load of 20 pounds per square foot is the requirement for an airplane of this type and the

vertical tail surfaces withstood a loading of 27.5 pounds per square foot without failure, the surfaces are satisfactory structurally.

The rudder-control system is likewise amply strong.

RECOMMENDATIONS.

Although the rudder-control system of the JL–6 monoplane is adequate for an airplane of this type, it is recommended that a standard control system be designed for this airplane. This would eliminate lost motion in the joints.

FUSELAGE.

DESCRIPTION.

The fuselage of the JL–6 is entirely of metal construction. The engine support and entire front end is constructed of channel sections, "I" sections, and tubular members. The members are all fastened together by riveting. There are no longerons. Corrugated sheet duralumin riveted to the structure forms the fuselage covering. Nine transverse bulkheads stiffen the fuselage structure.

Figure 65 is a picture of the fuselage. Figure 45 is a drawing of the bulkhead supporting the elevator control walking beam. This bulkhead failed while the elevator was being tested.

The following figures show the fuselage bulkheads and their construction:

Figure 38.—Bulkhead No. 1.
Figure 39.—Bulkhead No. 1 details.
Figure 40.—Bulkhead No. 2.
Figure 41.—Bulkhead No. 3.
Figure 42.—Bulkhead No. 4.
Figure 43.—Bulkhead No. 5.
Figure 44.—Bulkhead No. 6.
Figure 45.—Bulkhead No. 7.
Figure 46.—Bulkhead No. 8.
Figure 47.—Bulkhead No. 9.
Figure 48.—Diagonal bulkhead (tail skid elastic support).
Figure 49.—Bulkhead No. 10.
Figure 50.—Stern post of fuselage.
Figure 51.—Fuselage bulkhead (positions).
Figure 52.—Fuselage door.
Figure 53.—Fuselage door lock.
Figure 55.—A picture of the center section of the fuselage with the lower cover removed. The method of bracing may be seen.

PROCEDURE.

The fuselage was set up (less wings and tail surfaces) for the test and loaded according to the loading schedule in Figure 36. The loads were concentrated as indicated by the letters A, B, C, D, etc., in Figure 36. The deflection readings were taken after each half factor of the load had been allowed to remain in place for a period of five minutes. These deflections may be seen in Figure 37.

RESULTS.

The fuselage withstood a load factor of 4.5 without any considerable distortion, but when a load factor of 5 was reached the rear part of the fuselage buckled along the side seams.

At a load factor of 7 the front end of the fuselage (the engine bed and supports) collapsed. The structure was then counterbalanced and the load on the rear (equivalent to the same factor 7) was allowed to settle and the rear portion collapsed. The first failure occurred before the jacks supporting the rear load had been fully released. The second failure occurred just back of the cabin.

The deflections are tabulated in Figure 37. Figure 59 is a picture of the failure of the front end of the fuselage. Figure 62 is a picture of the failure of the rear part of the fuselage. Figure 63 is a picture of the same failure with the covering removed and bulkhead No. 4 exposed.

DISCUSSION.

A fuselage for an airplane of this type is required to stand a load factor of 5. Although the JL–6 fuselage showed signs of buckling at this loading, it did not fail until a load factor of 7 was imposed. The fuselage of the JL-6 is amply strong and well designed.

RECOMMENDATIONS.

It is recommended that reinforcing strip be riveted in the fuselage around the bulkhead which carries the rear walking beam of the elevator controls. This would eliminate failure similar to the one in the elevator test.

INVESTIGATION OF JL–6 WING MEMBERS.

After checking the sizes of the wing members of the JL–6 with the sizes of the wing members of the Junker biplane (which was previously tested) it was found unnecessary to repeat the testing of these parts, since the same size members are used in both airplanes. However, a few check tests were made, the results of which are herewith tabulated.

	Duralumin tube.	Ball-and-socket joint.	
		Small tube.	Large tube.
Specimen marked	1	2A	2B
Diameter, inches	1.562	1.973	2.364
Thickness, inches	.061	.062	.059
Area, square inches	.2876	.37222	.42724
Area corrected for rivet holes	....	.34457	....
Yielding point, pounds per square inch	39,600	44,260	....
Ultimate strength pounds per square inch	52,500	53,720	....
Elongation, per cent in 2 inches	13.0	....	....
Elongation, per cent in 4 inches	12.5	....	....
Elongation, per cent in 8 inches	10.0	....	....
Location of fracture	O. T.	Tube.	None.
Character of fracture	Diagonal; jagged.	Square.	....

NOTE.—Ball-and-socket joint was O. K. Failure occurred in small tube through rivet holes.

These test results check very favorably with the physical properties of the specimens of the Junker biplane published in McCook Field Report, Serial No. 1412.

An interesting feature of the ball-and-socket wing joint is the fact that on the high-incidence static wing test some of the joints failed at the threads, while others failed on either side of the joint in the spar itself. The wing joints are very well designed.

The chemical composition of the duralumin used in the Junker airplanes is as follows:

Silicon	0.51
Copper	3.34
Iron	.81
Magnesium	.59
Manganese	.15
Aluminum	94.60

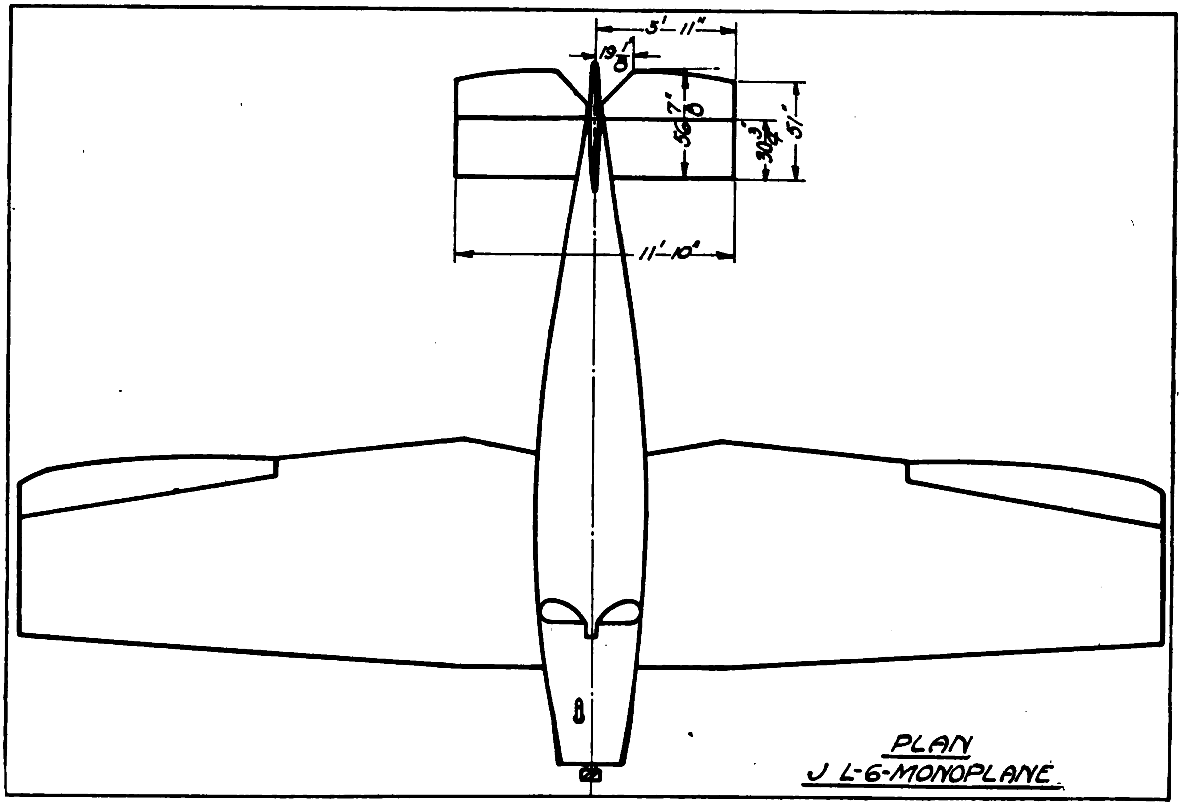

5'–11"
19 1/8
7' 0
56
30 3/4
51'
11'–10"
PLAN
J L-6-MONOPLANE

FIG. 1.

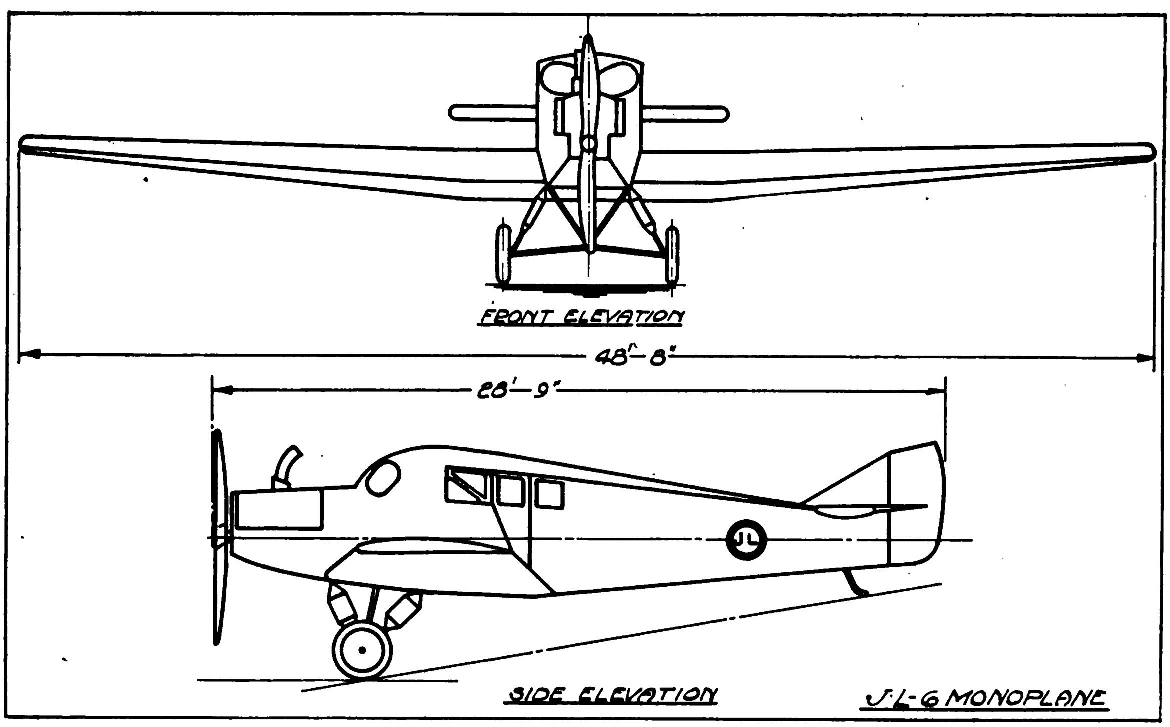
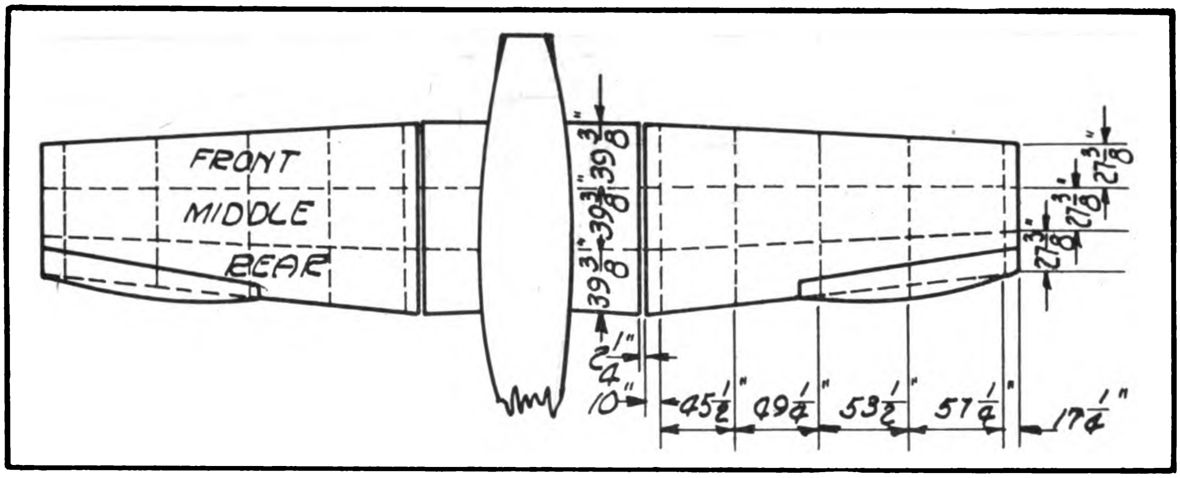

FRONT ELEVATION
48'–8"
28'–9"
JL
SIDE ELEVATION
J-L-6 MONOPLANE

FIG 2.



LOADING SCHEDULE FOR LOW INCIDENCE ANGLE.

Load factor.	Load (in pounds) over each section of the wings.			Total load on wing.
	F	M	R	
2	580	2,890	2,310	5,780
2.5	740	3,690	2,940	7,370
3	900	4,490	3,570	8,960
3.5	1,060	5,290	4,200	10,550

Wings held and test was discontinued.

FIG. 3.—J L-6 wing.

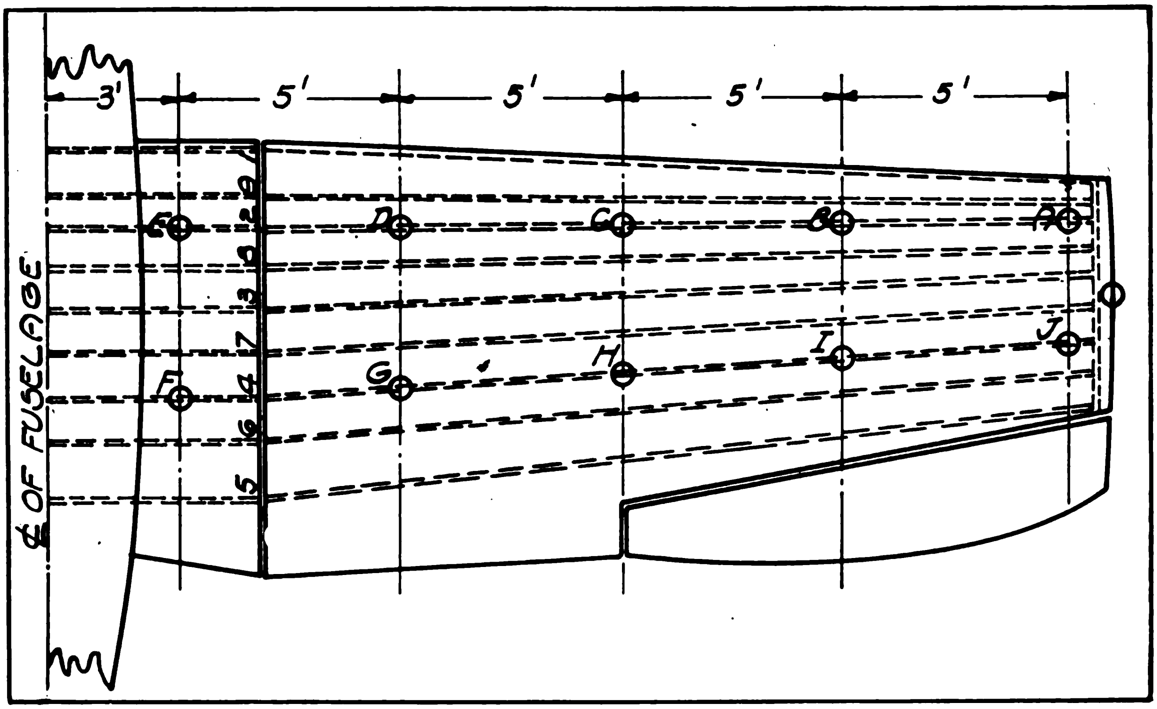


TABLE OF DEFLECTIONS OF THE RIGHT WING FOR THE LOW INCIDENCE ANGLE.

Load factor.	Deflections in inches measured at—										Retreat.
	A	B	C	D	E	F	G	H	I	J	Y
2	4.5	3.2	2.7	1.0	0.5	4.7	3.6	2.3	1.3	0.5	+0.1
2.5	5.8	3.9	2.7	2.4	.6	5.9	4.1	2.8	1.6	.6	+.2
3.0	7.1	4.9	3.2	1.7	.6	7.1	5.3	3.4	2.1	.7	+.2
3.5	8.5	6.0	3.9	2.0	.8	8.7	6.3	4.1	2.4	.9	−.1

Test discontinued.

FIG. 4.—J L-6 monoplane.

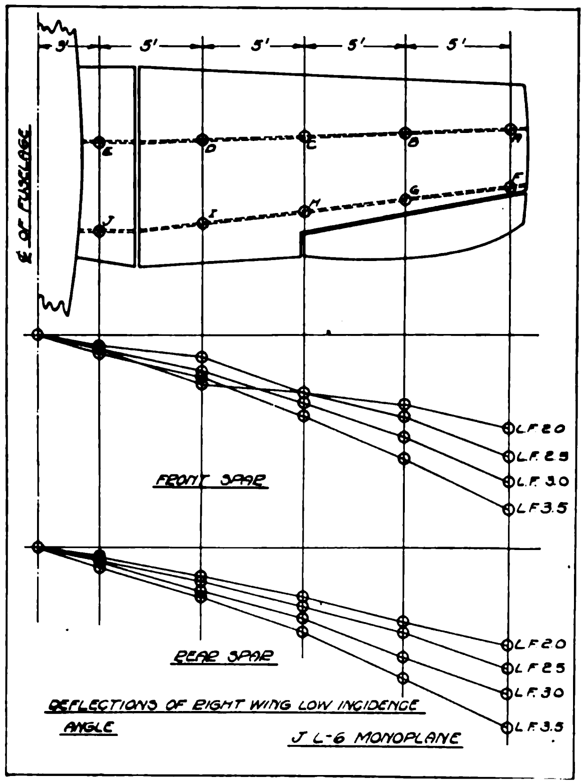
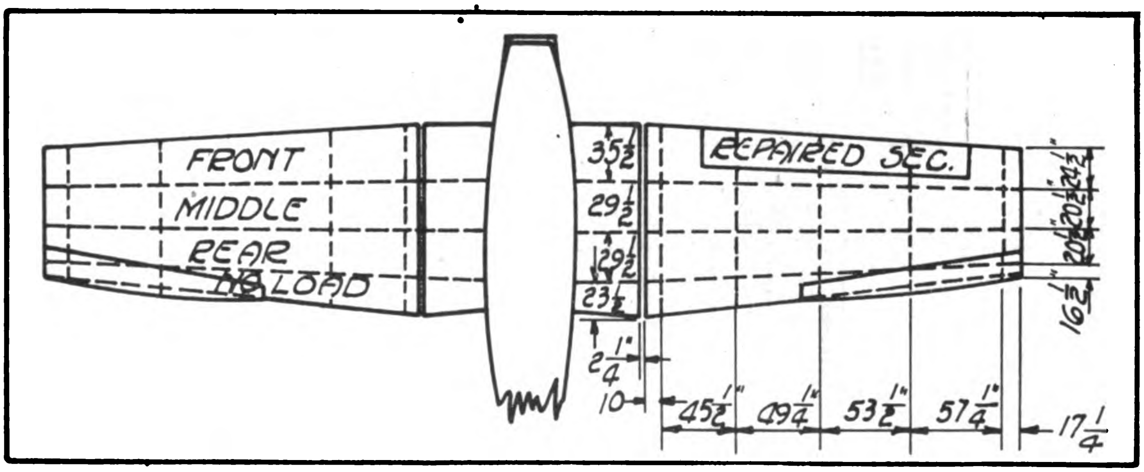


FIG. 5.



LOADING SCHEDULE FOR HIGH INCIDENCE ANGLE.

Load factor.	Load (in pounds) over each section of the wings.			Total load on wing.
	F	M	R	
2	2,890	1,450	1,440	5,780
3	4,480	2,250	2,230	8,960
3.5	5,280	2,650	2,620	10,550
4	6,080	3,050	3,010	12,140
4.5	6,880	3,450	3,400	13,730
5	7,680	3,850	3,790	15,320
5.5	8,480	4,250	4,180	17,910
6	9,280	4,650	4,570	18,500
6.5	10,080	5,050	4,960	20,090

FIG. 6.—JL-6 monoplane.

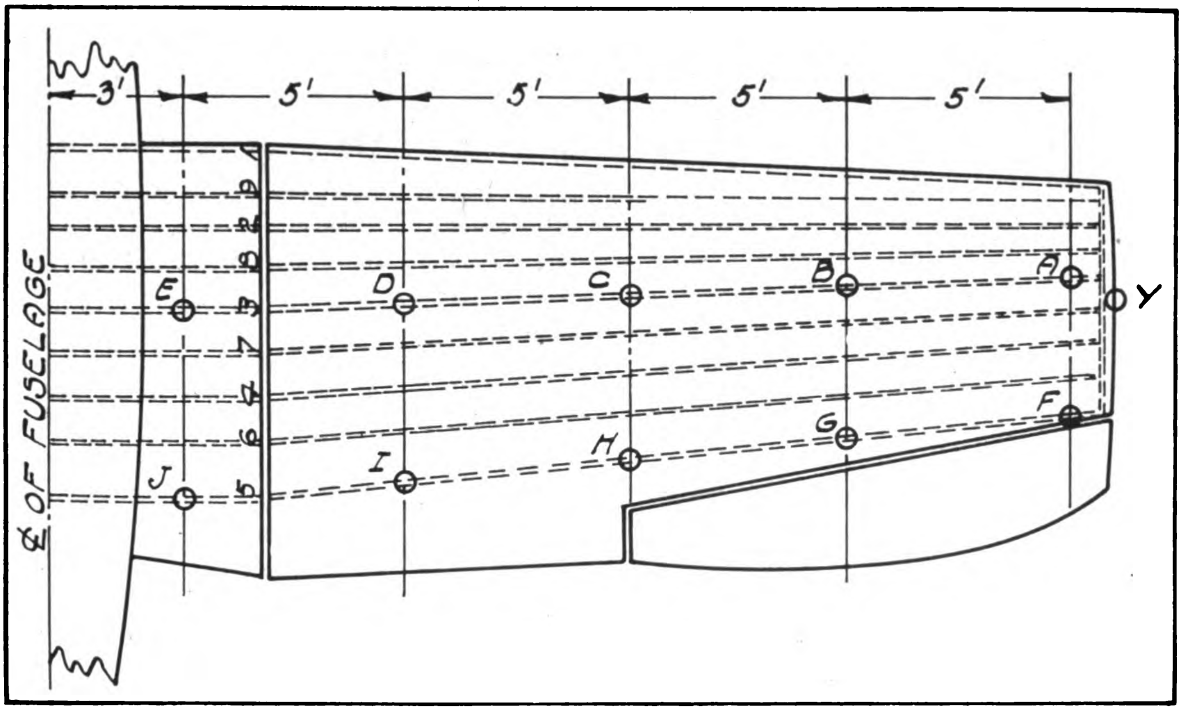


TABLE OF DEFLECTIONS OF THE RIGHT WING FOR THE HIGH INCIDENCE ANGLE.

Load factor.	Deflections, in inches, measured at—										Retreat.
	A	B	C	D	E	F	G	H	I	J	Point Y.
2	3.6	2.5	1.5	0.9	0.4	0.6	1.1	2.0	2.9	4.1	+0.8
3	5.5	3.9	2.4	1.3	.5	.8	1.7	3.1	4.5	6.4	+1.4
3.5	6.2	4.3	2.7	1.4	.5	.9	2.1	3.7	5.5	8.0	+1.1
4	7.1	4.9	3.0	1.6	.6	1.1	2.4	4.7	6.4	9.4	+1.3
4.5	8.1	5.7	3.4	1.8	.7	1.2	2.8	5.1	7.5	10.9	+1.5
5	9.6	6.6	4.0	2.0	.7	1.2	3.2	5.8	8.5	12.3	+1.3
5.5	12.7	7.6	4.6	2.3	.9	1.3	3.5	6.5	9.8	13.9	+2.0
6	Deflection readings discontinued.										
6.5	Failure.										
7	....	....	....	....	....	....	....	....	....	....	....

FIG. 7.

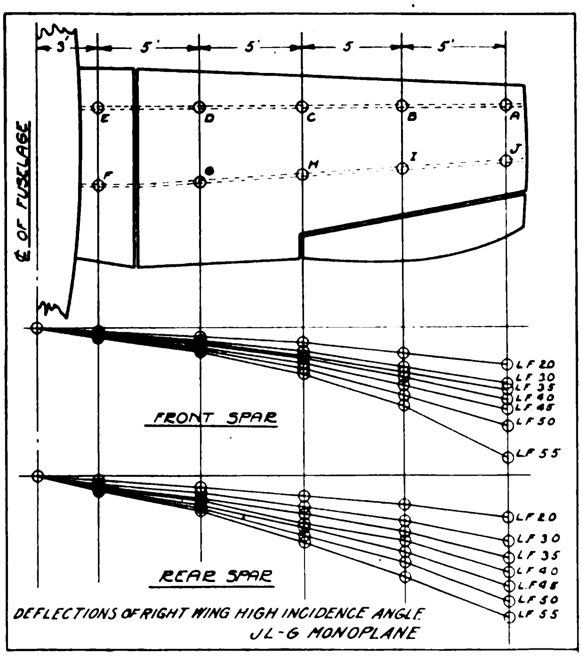


FIG. 8.

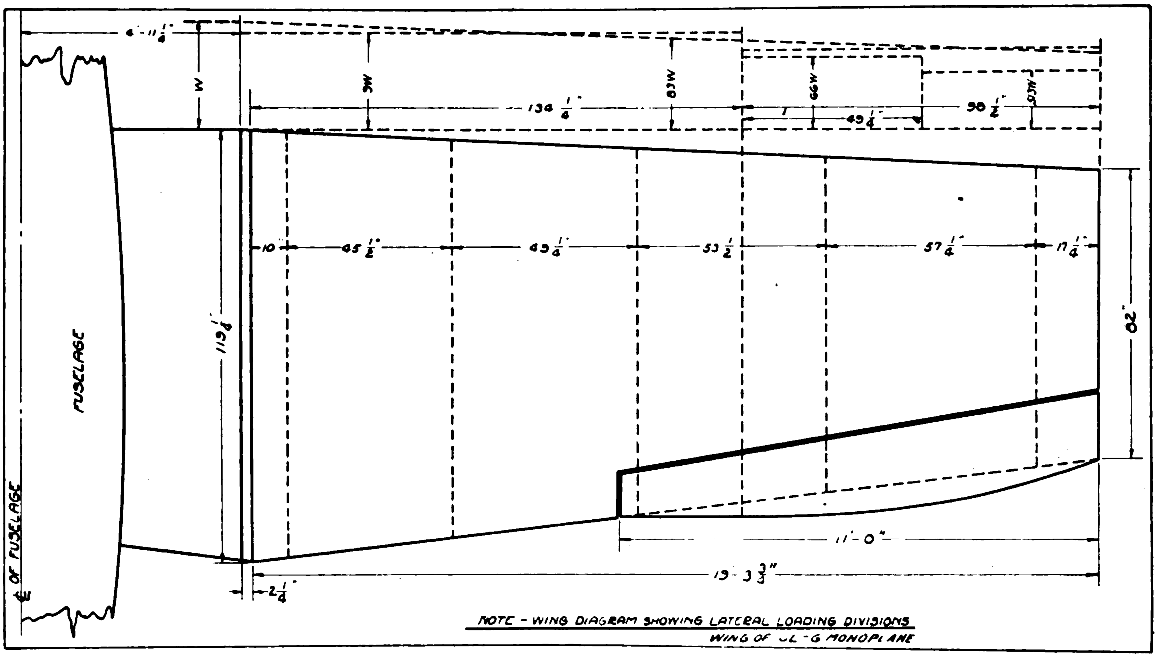
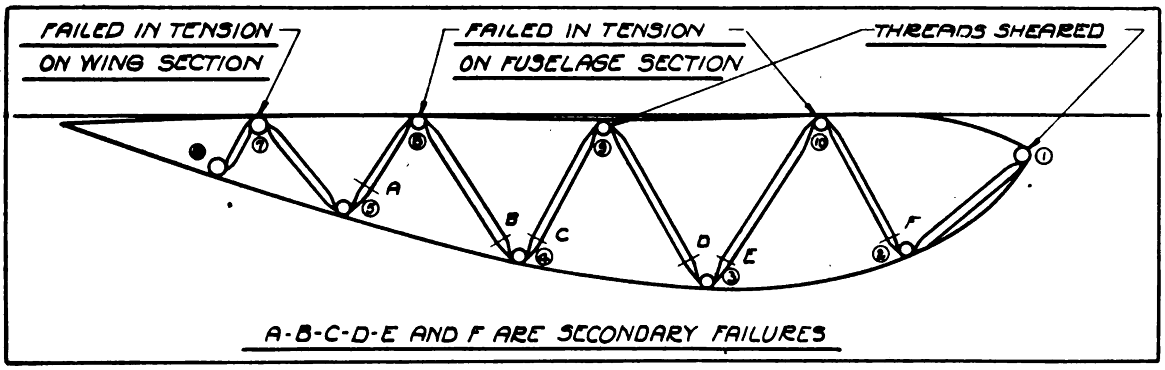


FIG. 9.



NOTE: Diagram of the spar failures of the right wing at the junction of center section. Sketch shows wing inverted as for test.

FIG. 10.

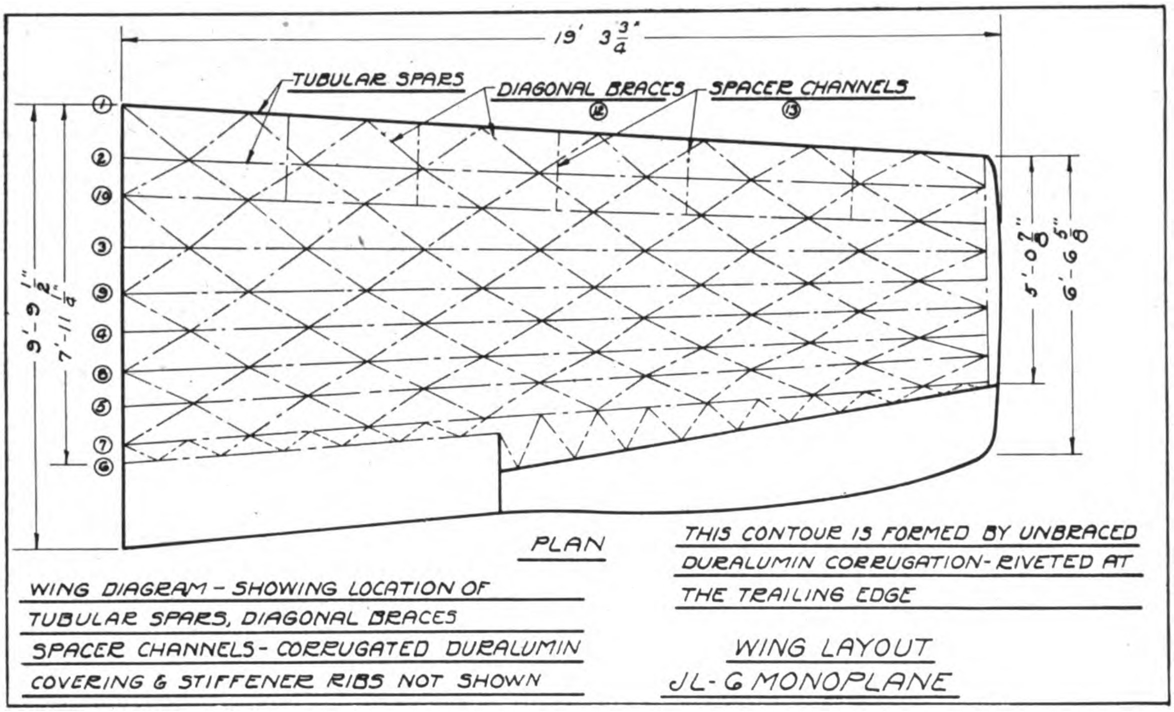

19' 3 3/4"
TUBULAR SPARS
DIAGONAL BRACES
SPACER CHANNELS
9'-9 1/2"
7'-11 1/4"
5'-0 7/8"
6'-6 5/8"
PLAN
THIS CONTOUR IS FORMED BY UNBRACED
DURALUMIN CORRUGATION-RIVETED AT
THE TRAILING EDGE
WING DIAGRAM - SHOWING LOCATION OF
TUBULAR SPARS, DIAGONAL BRACES
SPACER CHANNELS - CORRUGATED DURALUMIN
COVERING & STIFFENER RIBS NOT SHOWN
WING LAYOUT
JL-6 MONOPLANE

FIG. 11.

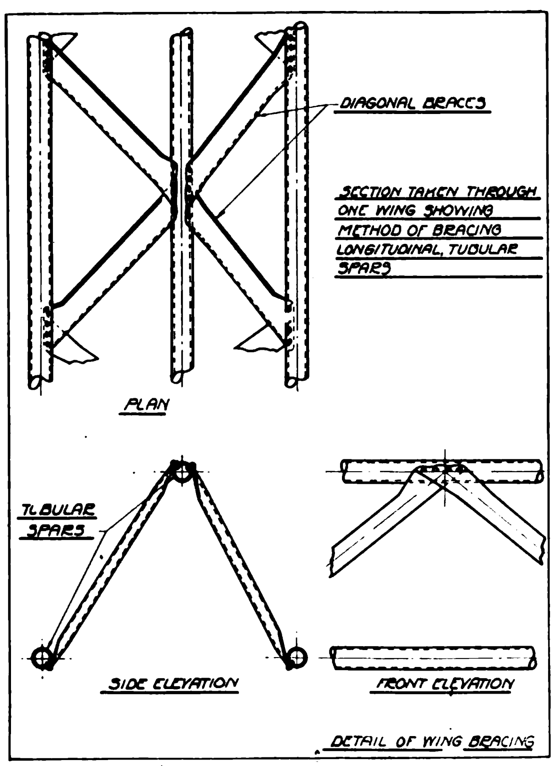

DIAGONAL BRACES
SECTION TAKEN THROUGH
ONE WING SHOWING
METHOD OF BRACING
LONGITUDINAL, TUBULAR
SPARS
PLAN
TUBULAR
SPARS
SIDE ELEVATION
FRONT ELEVATION
DETAIL OF WING BRACING

FIG. 12.

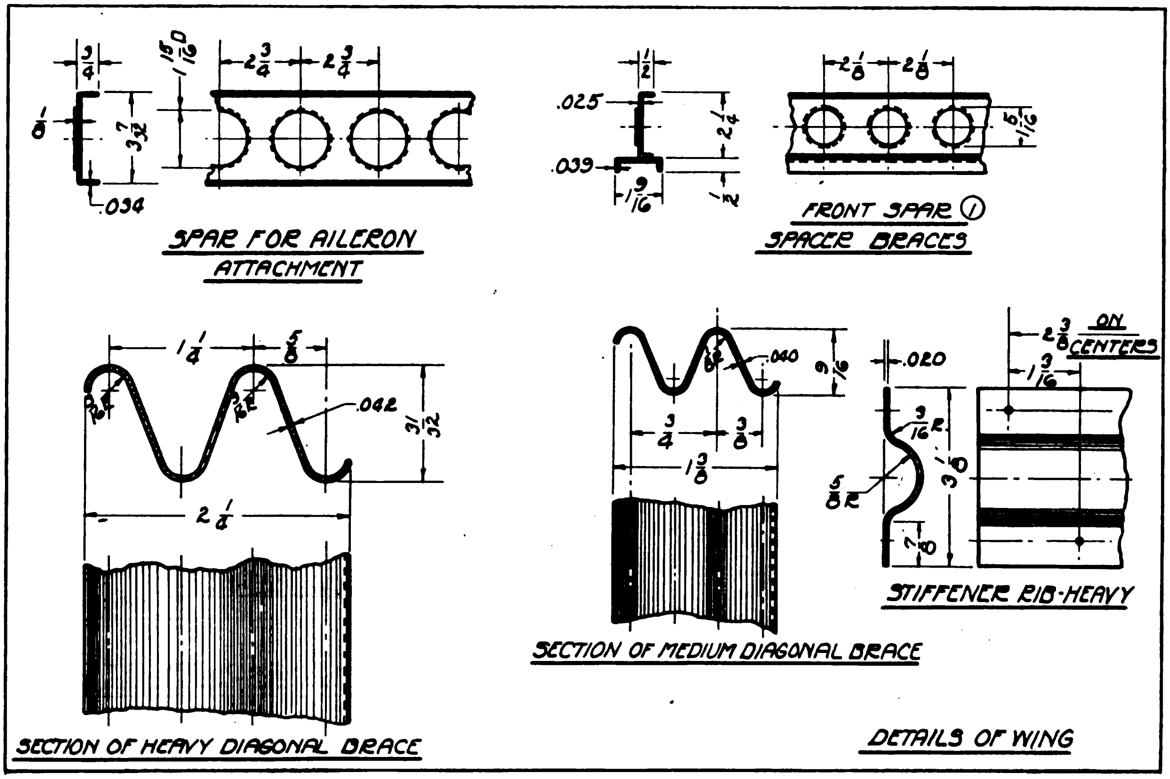
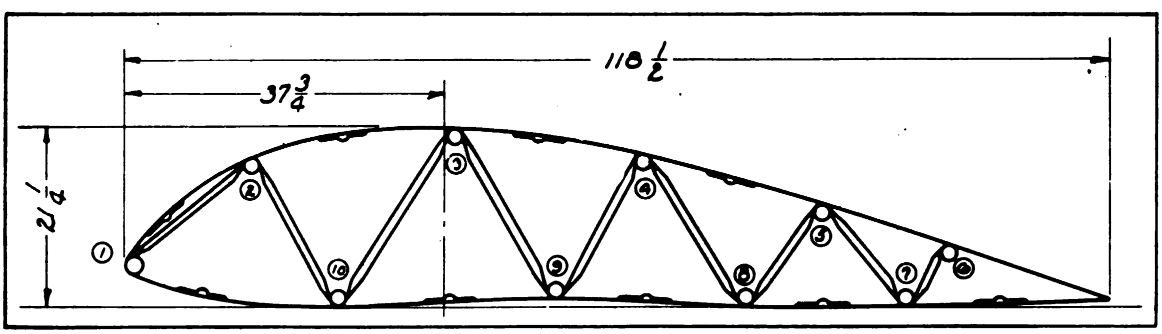


FIG. 13.



Note: Section of wing at point of connection to center section showing location of tubular spars and diagonal braces and stiffener ribs.

FIG. 14.—Section at wing joint.

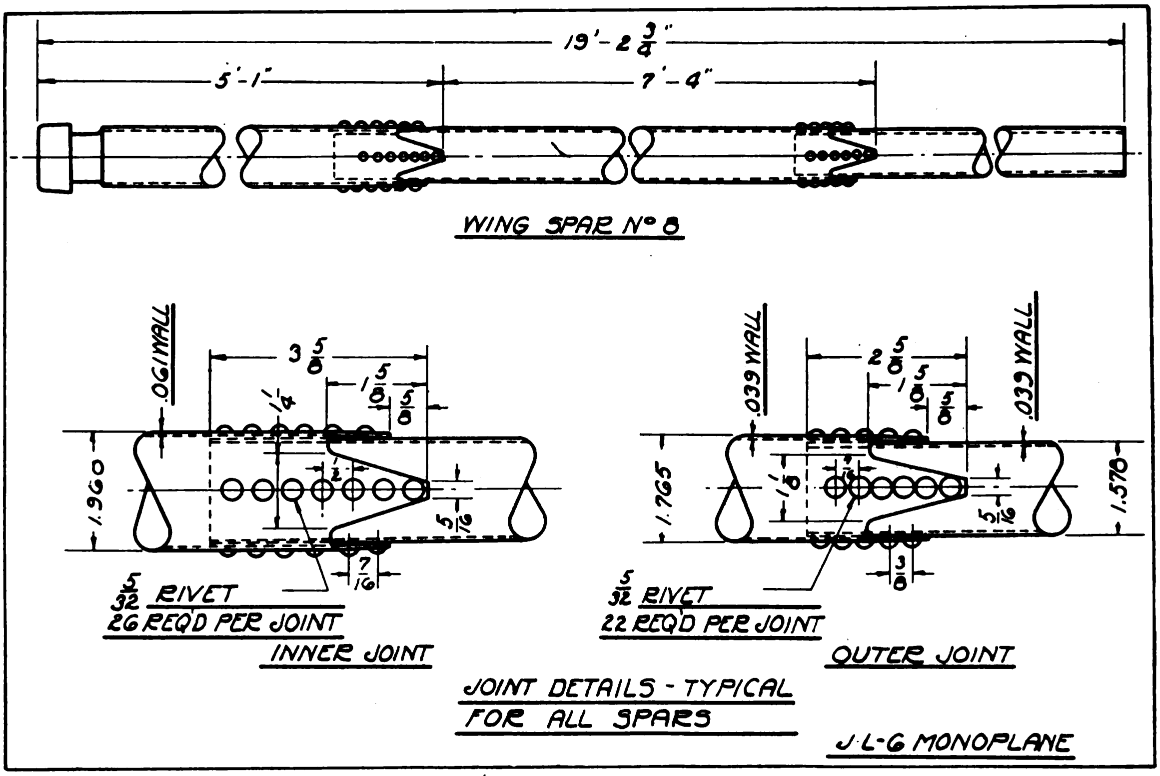


Fig. 15.

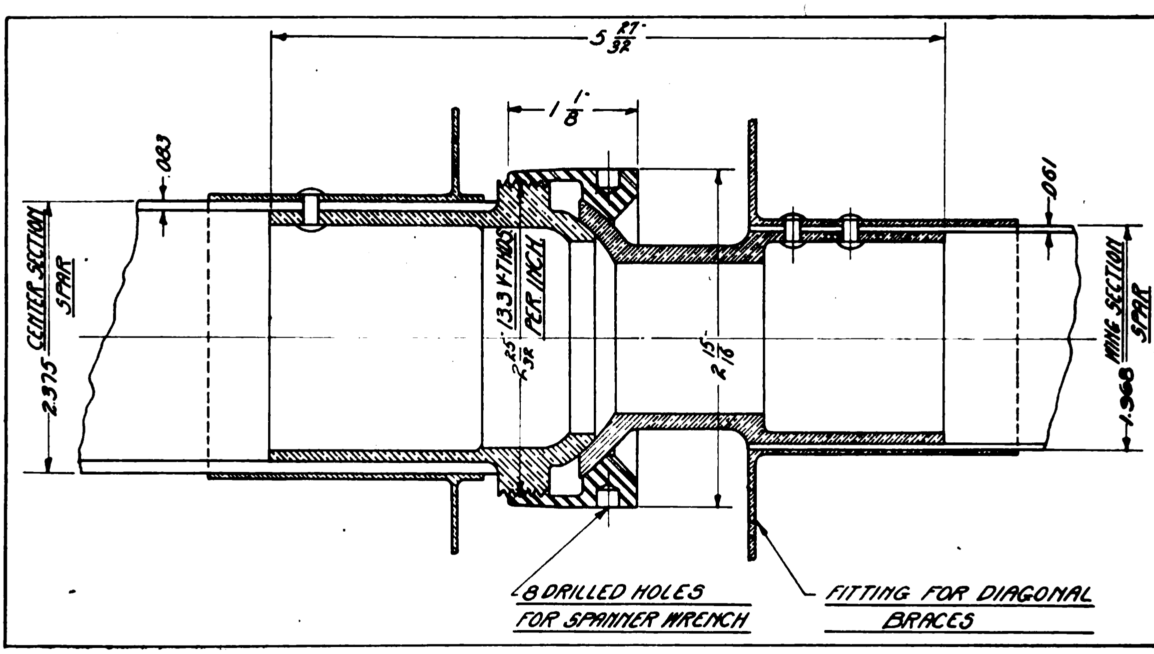


Fig. 16.—Assembly of wing joint.

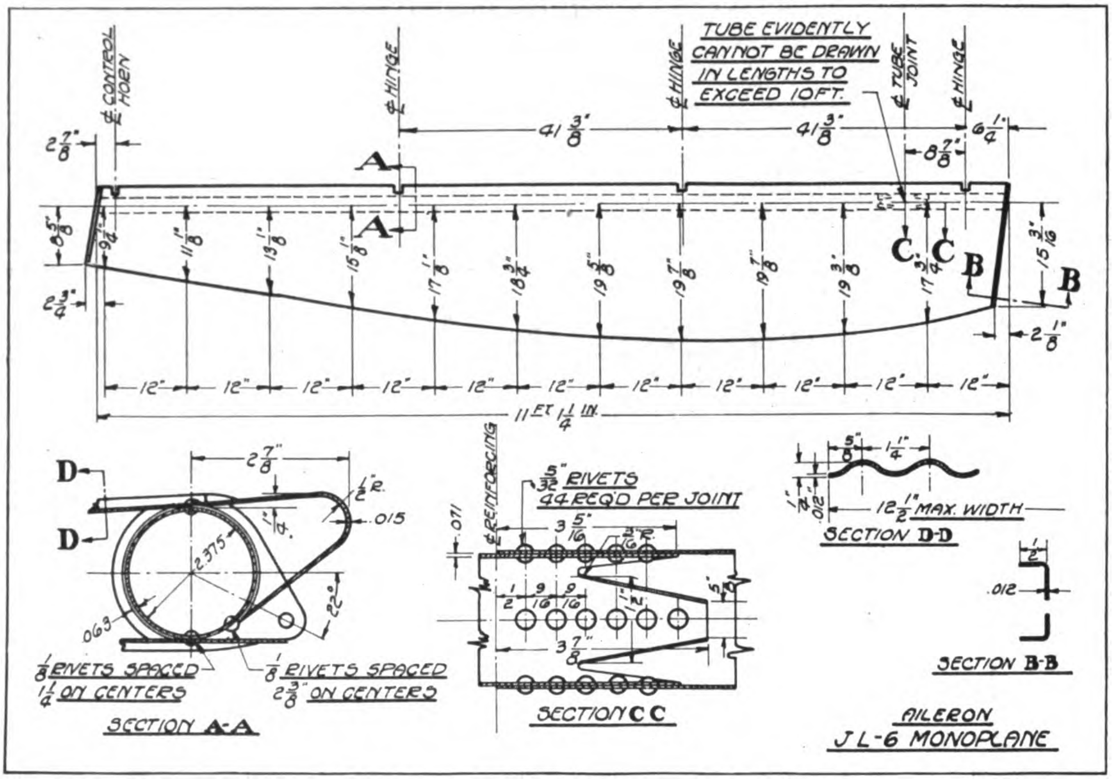


FIG. 17.

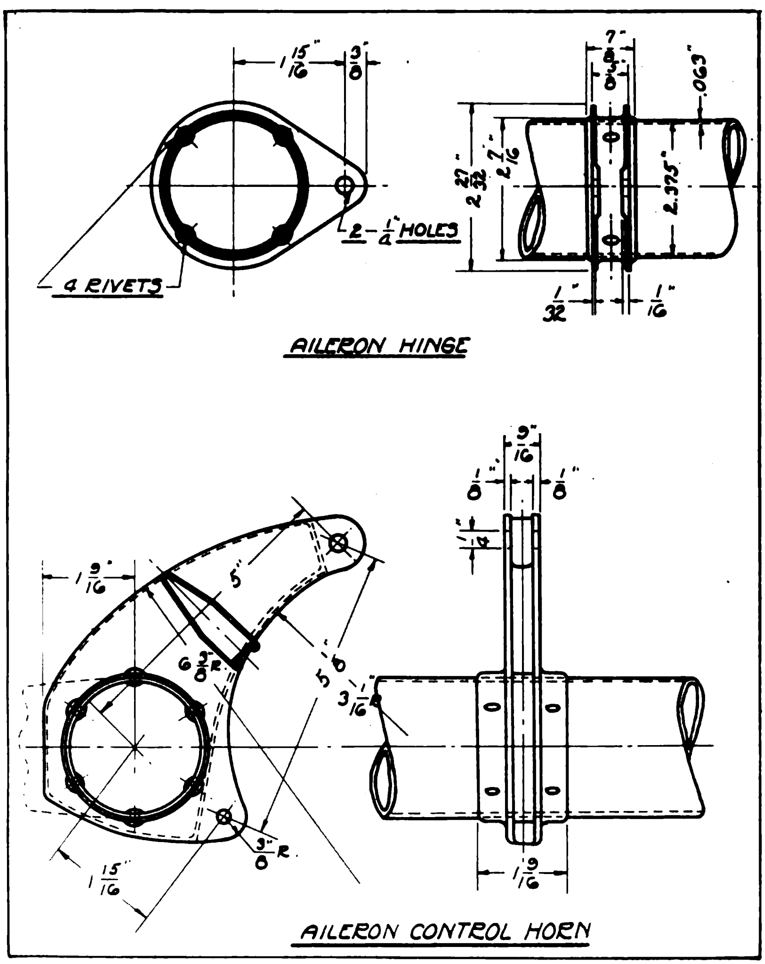
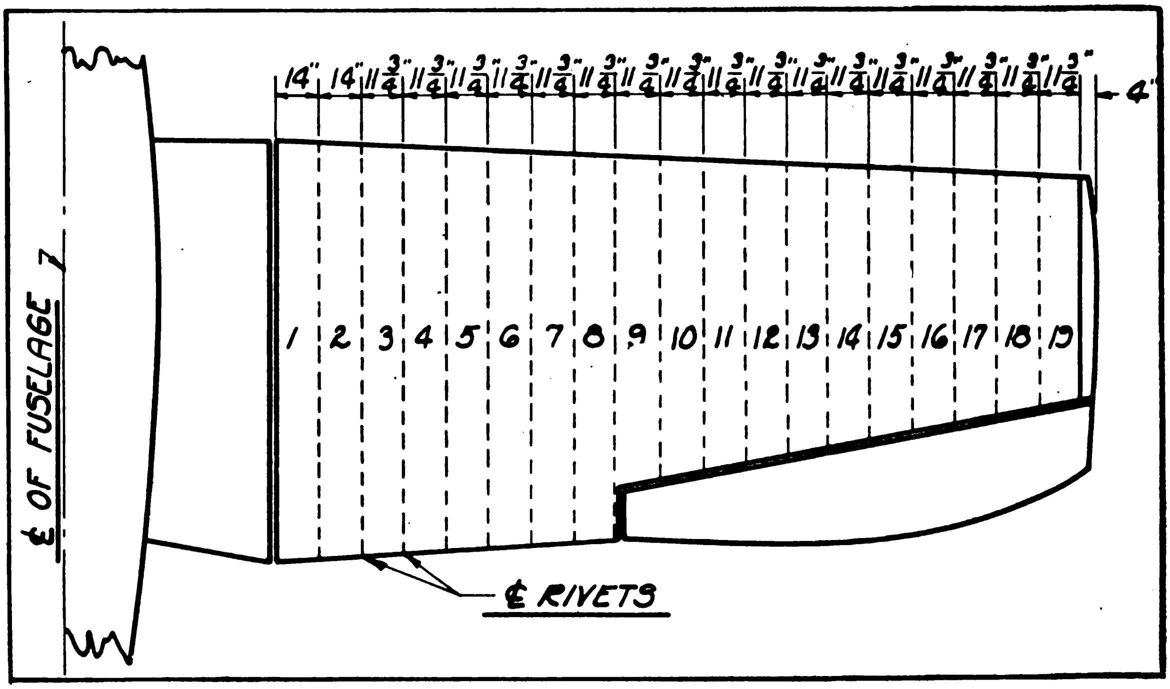


FIG. 18.—Aileron details.



Section.	Thickness. Top cover.	Thickness. Bottom cover.	Section.	Thickness. Top cover.	Thickness. Bottom cover.
1	0.021	0.021	11	0.012	0.012
2	.021	.021	12	.012	.012
3	.016	.016	13	.012	.012
4	.016	.016	14	.012	.012
5	.016	.016	15	.012	.012
6	.016	.016	16	.012	.012
7	.016	.016	17	.012	.012
8	.012	.012	18	.012	.012
9	.012	.012	19	.012	.012
10	.012	.012			

FIG. 19.—Thickness of wing covering.

TABLE OF WEIGHTS AND AREAS.

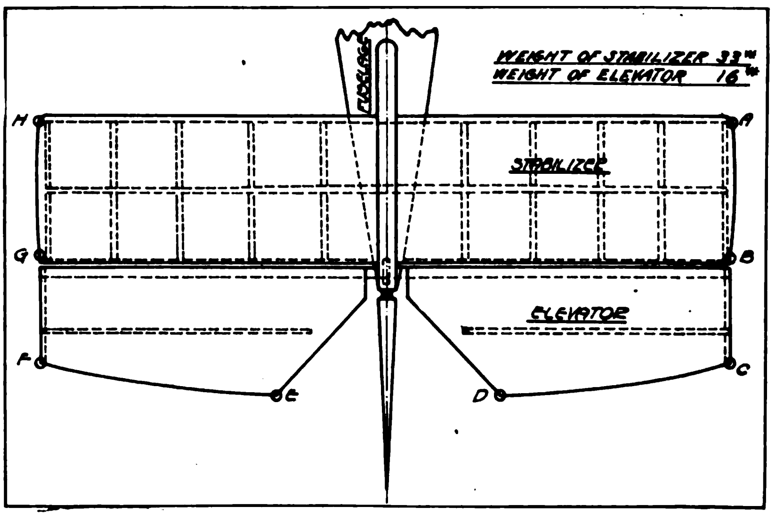
Item.	Weight in pounds.	Area in square feet.	Pounds per square foot.	Remarks.
2 wings with ailerons	428	335.2	1.278	Wing area from wing joint out to tip.
2 ailerons	30	35.4	.85	
Center section	168	92.4	1.825	Section between wing joints included under fuselage.
Wing area under fuselage	....	42	....	Part of fuselage bottom.
Total area from tip to tip	....	430	....	Including part of wing which forms fuselage bottom.
Stabilizer	33	28	1.17	Stabilizer built in one piece.
Elevator	16	20.8	.77	Both sides built on same spar.
Rudder	9.5	11.5	.82	
Fin	5	5	.94	
Tail skid	6.94	....	....	Built up of sheet steel.
Total weight of airplane as in flight	3,910	(1)	10.9	Weight is with pilots, passengers, gas, water, oil, instruments, etc.
Total area of wings, including fuselage section	596	385.6	1.54	

[1] Total area, 385.6, effective.

TABLE OF WEIGHTS OF CORRUGATED DURALUMIN.

Thickness.	¼ square foot.	1 square foot.	Remarks.
Inch.	*Pound.*	*Pound.*	
0.021	0.085	0.340	With paint on.
.016	.070	.280	Do.
.012	.050	.200	Do.
.021	.080	.320	Do.
.016	.060	.240	Do.
.012	.040	.160	Do.

FIG. 20.



RESULTS OF STATIC TEST OF ELEVATOR AND STABILIZER.

Load factor.	Deflections measured at points— A	B	C	D	E	F	G	H	Pull on stick.	Load per square foot on— Elevator. Added.	Elevator. Total.	Stabilizer. Added.	Stabilizer. Total.	Remarks.
									Pounds.	*Pounds.*	*Pounds.*			
1	0.1	0.2	0.3	0.1	0.2	0.5	0.3	0.2	55	84	84	169	338	
2	.3	.5	2.1	2.2	2.4	2.1	.7	.3	100	84	168	169	507	
3	.5	.9	4.3	4.8	5.0	4.3	1.1	.6	150	84	252	169	686	Control stick bending control.
4	1.0	1.2	3.3	5.3	6.7	5.1	1.1	.8	....	84	336	169	855	Stick torque tube failed in bending.
4.5	1.1	1.0	4.2	6.4	7.9	6.0	1.1	1.4	....	42	378	84.5	939.5	Test continued on rear control.
5	Deflections discontinued.								....	42	420	84.5	1,024.0	Failure of bulkhead supporting walking beam between first and second linkage of elevator control. Both rivets tore loose and the metal tore. Surfaces showed no signs of failure during test.
5.5	......	......	......	......	......	......	......	......	....	42	462	84.5	1,108.5	
6	......	......	......	......	......	......	......	......	....	42	504	84.5	1,193.0	
6.5	Failure.								....	42	546	84.5	1,277.5	

FIG. 21.

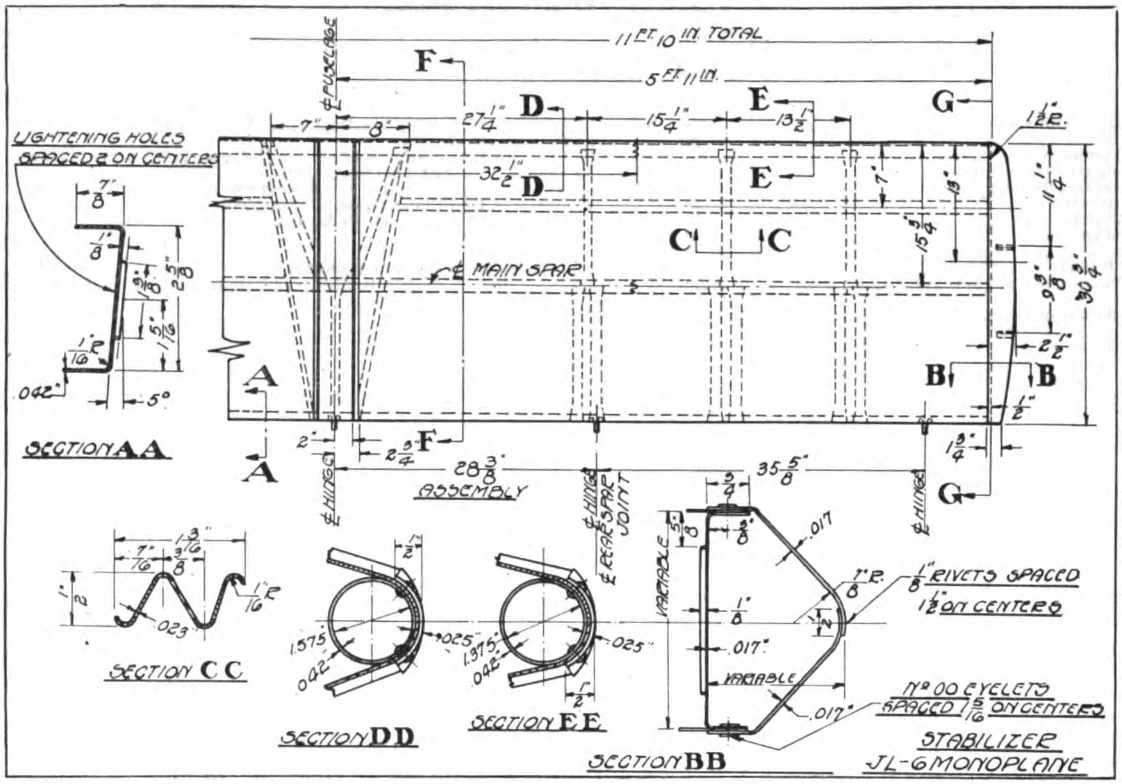

11 FT. 10 IN. TOTAL
5 FT. 11 IN.
LIGHTENING HOLES SPACED 2 ON CENTERS
℄ FUSELAGE
℄ MAIN SPAR
℄ HINGE
℄ HINGE ℄ REAR SPAR JOINT
ASSEMBLY
SECTION AA
SECTION CC
SECTION DD
SECTION EE
SECTION BB
VARIABLE
1/8" RIVETS SPACED 1 1/2" ON CENTERS
No. 00 EYELETS SPACED 1 5/16 ON CENTERS
STABILIZER
JL-6 MONOPLANE

FIG. 22.

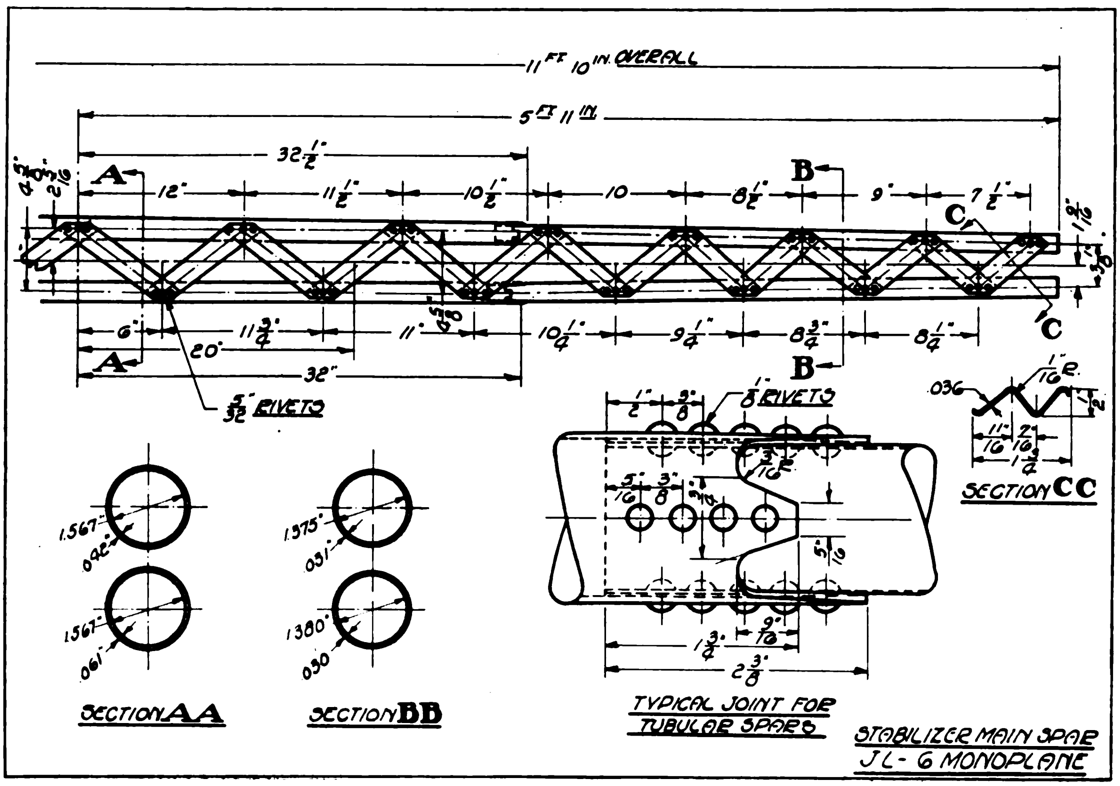

11 FT. 10 IN. OVERALL
5 FT. 11 IN.
5/32" RIVETS
1/8" RIVETS
SECTION AA
SECTION BB
SECTION CC
TYPICAL JOINT FOR TUBULAR SPARS
STABILIZER MAIN SPAR
JL-6 MONOPLANE

FIG. 23.

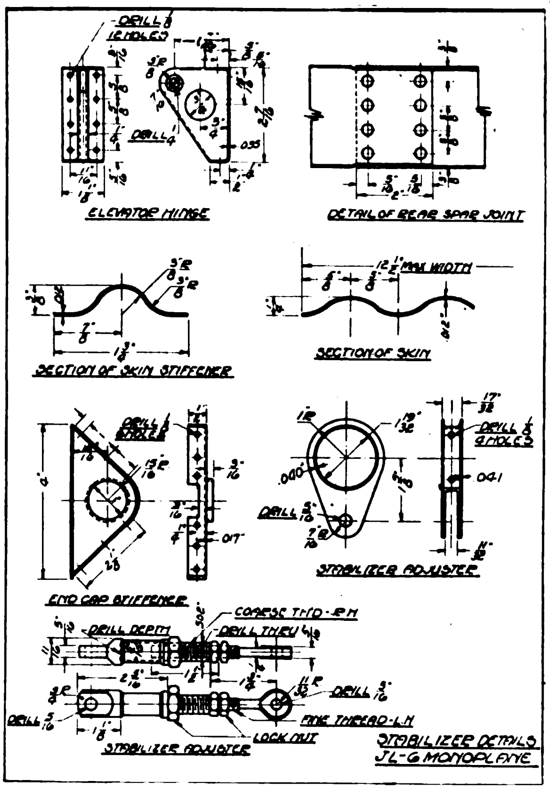


FIG. 24.

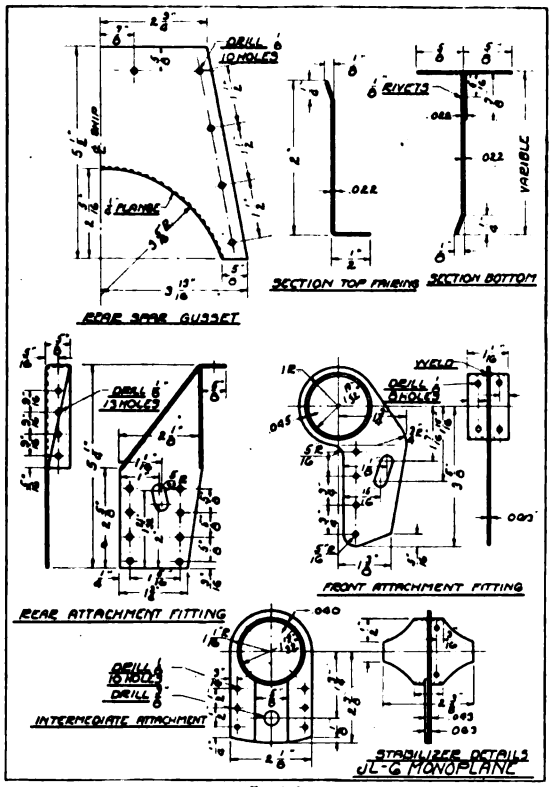


FIG. 25.

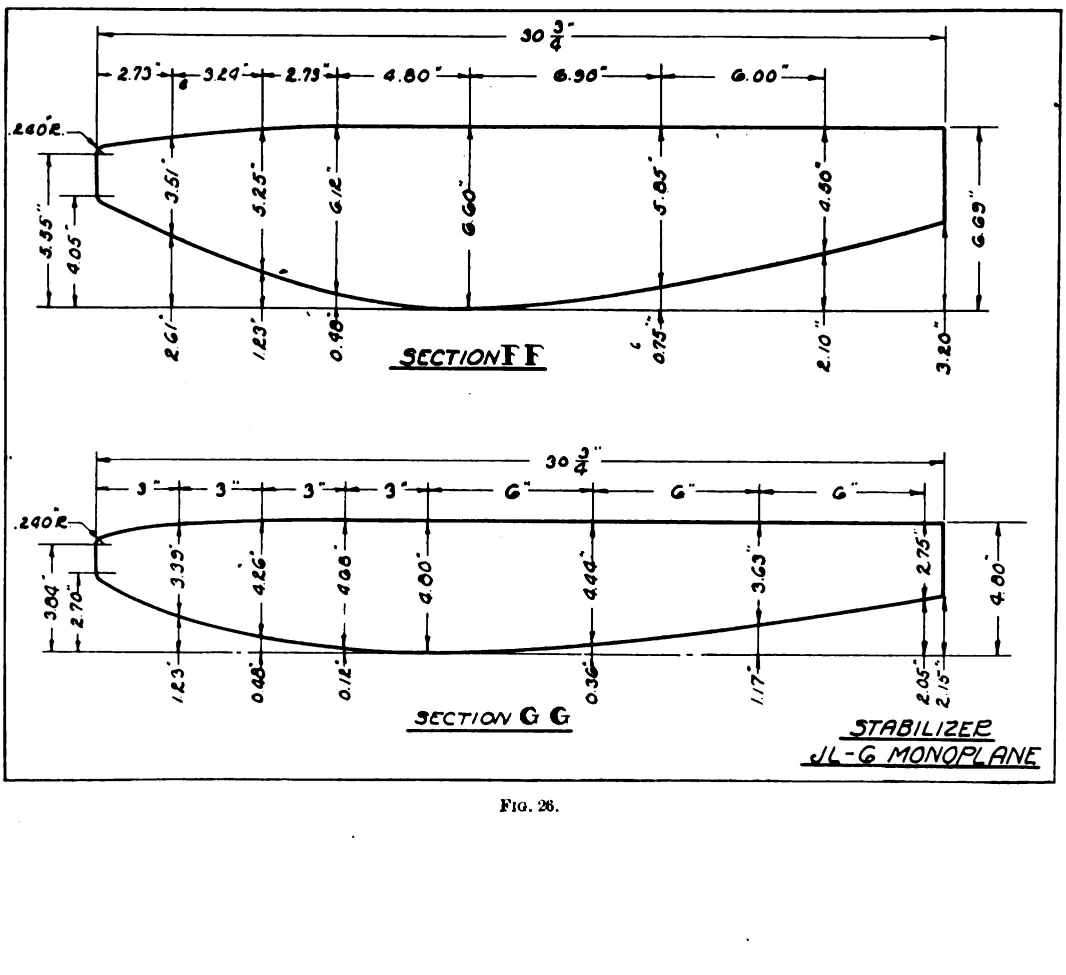


FIG. 26.

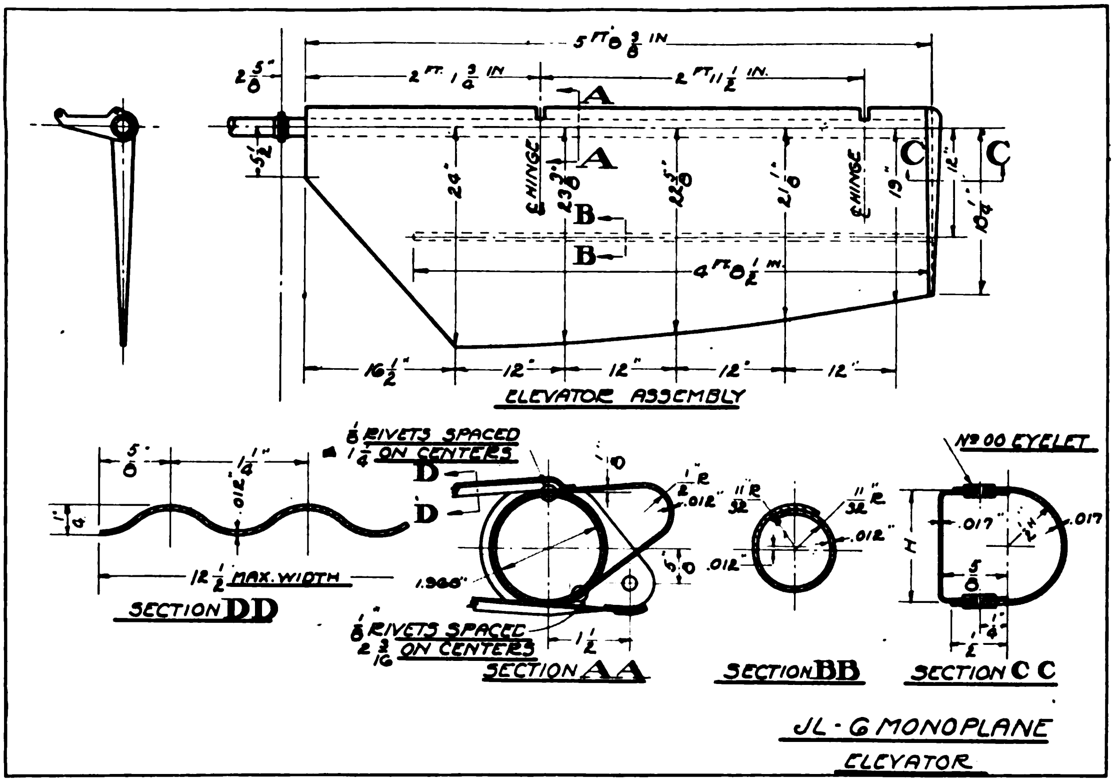

ELEVATOR ASSEMBLY
1/8 RIVETS SPACED 1 1/4 ON CENTERS
12 1/2 MAX. WIDTH
SECTION DD
1/8 RIVETS SPACED 2 3/16 ON CENTERS
SECTION AA
SECTION BB
No 00 EYELET
SECTION C C
JL-6 MONOPLANE
ELEVATOR

FIG. 27.

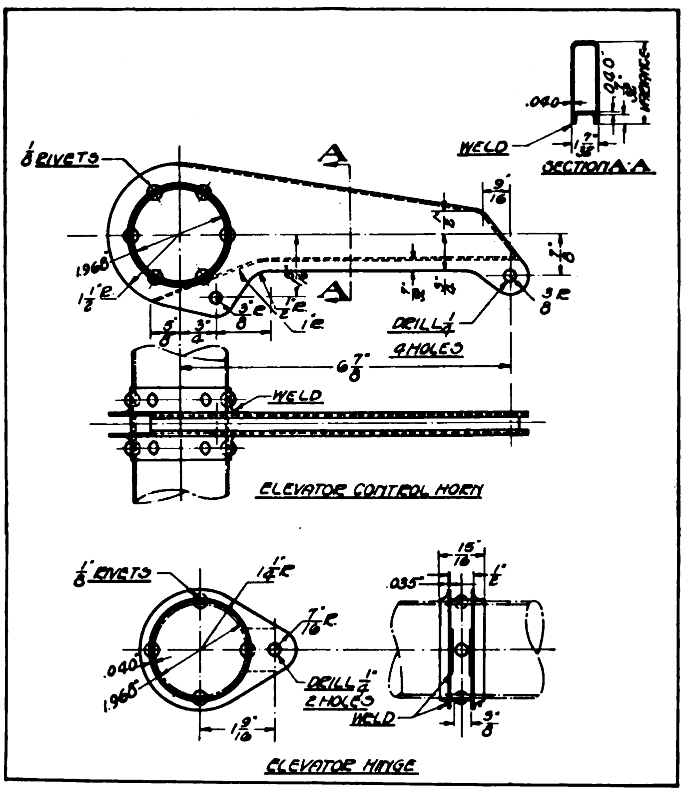
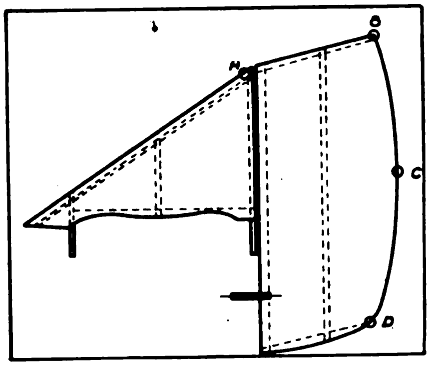

1/8 RIVETS
WELD
SECTION A-A
DRILL 1/4
4 HOLES
ELEVATOR CONTROL HORN
1/8 RIVETS
DRILL 1/4
2 HOLES
WELD
ELEVATOR HINGE

FIG. 28.



RESULTS OF RUDDER AND FIN TEST.

Load factor.	Pounds per square foot.	Deflection at— A	B	C	D	Pull on control.	Load per square foot on— Rudder. Added.	Rudder. Total.	Fin. Added.	Fin. Total.	Total load on vertical surfaces (pounds).
1	5	0.1	0.3	0.2	0.1	100	50.5	50.5	34	34	84.5
2	10	.3	2.4	2.5	1.9	180	50.5	101.0	34	68	169.0
3	15	.5	4.4	4.4	3.4	....	50.5	151.5	34	102	253.5
4	20	.7	6.5	6.6	5.1	....	50.5	202.0	34	136	338.0
4.5	22.5	.9	8.0	8.4	6.5	....	25.25	227.25	17	143	370.25
5	25		Failure.			....	25.25	252.5	17	220	472.5
5.5	27.5	....	....	....	....	....	....	....	....	....	....
6	30	....	....	....	....	....	....	....	....	....	....

NOTE.—When average load was 22.5 pounds per square foot left rudder control pedal twisted. At an average loading of 25 pounds per square foot the left rudder pedal of right control failed.

FIG. 29.

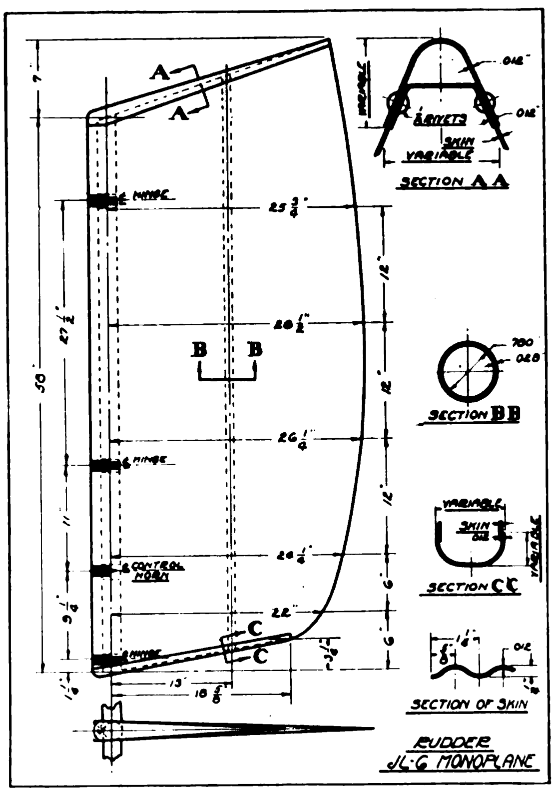


FIG. 30.

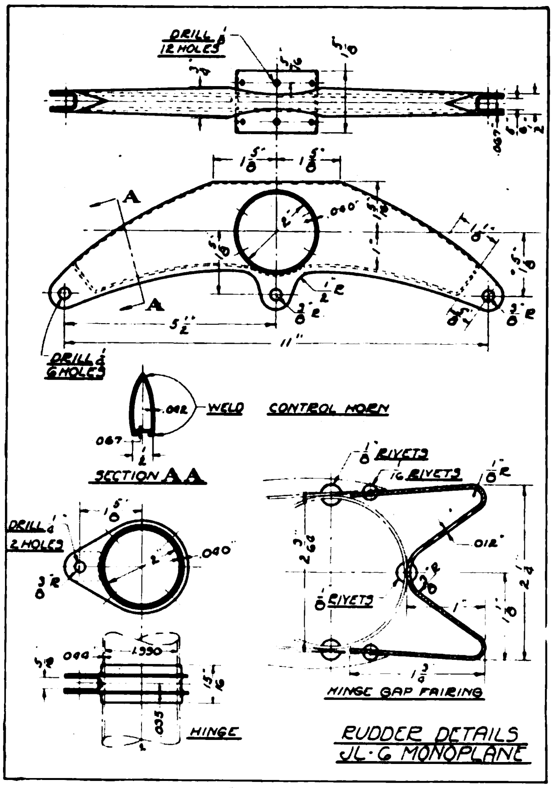


FIG. 31.

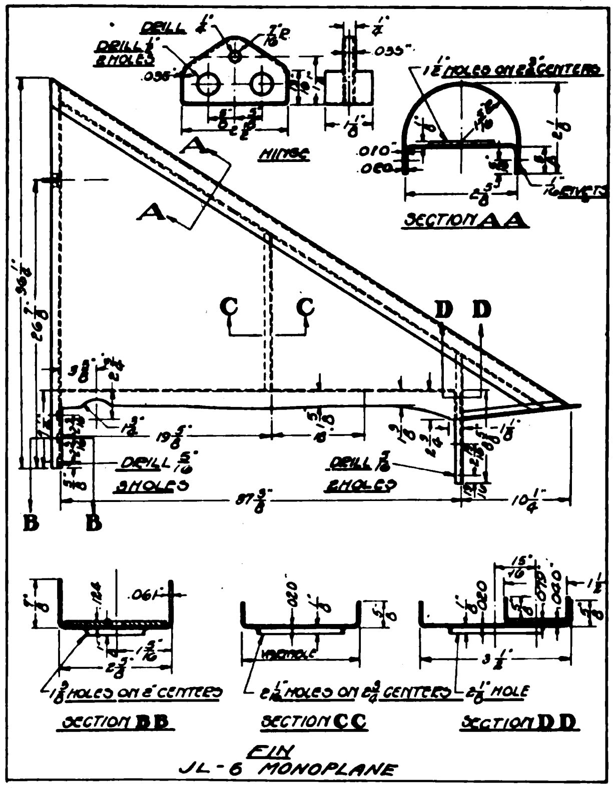


FIG. 32.

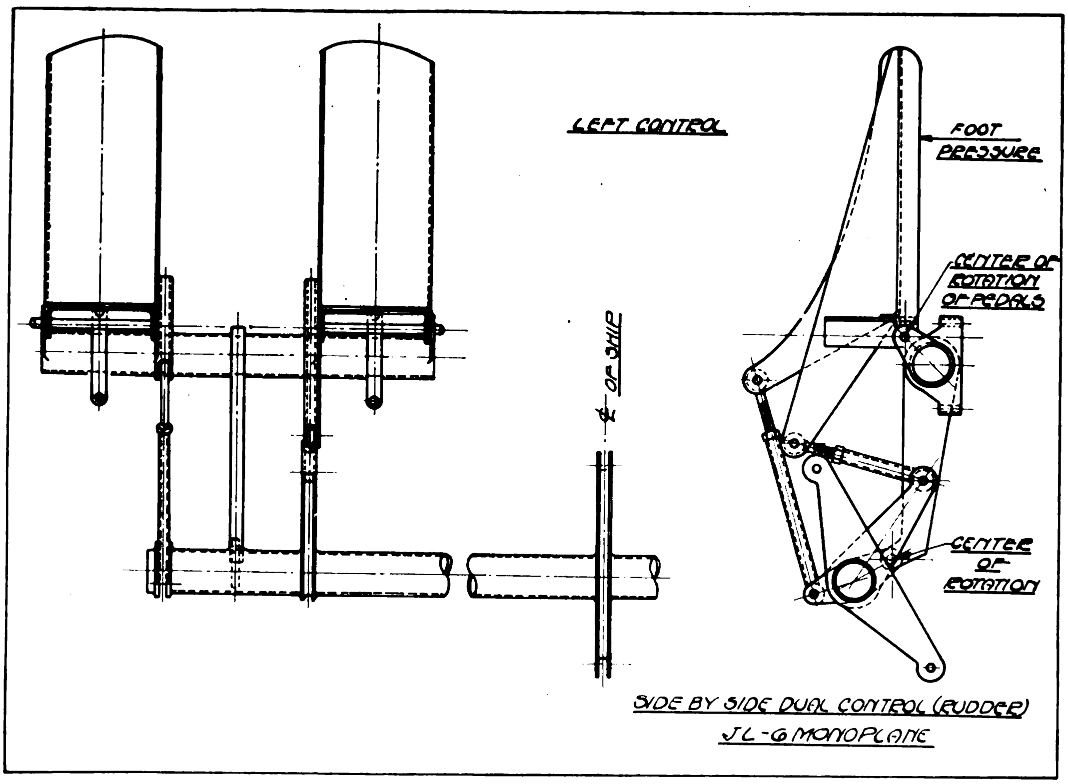


FIG. 33.

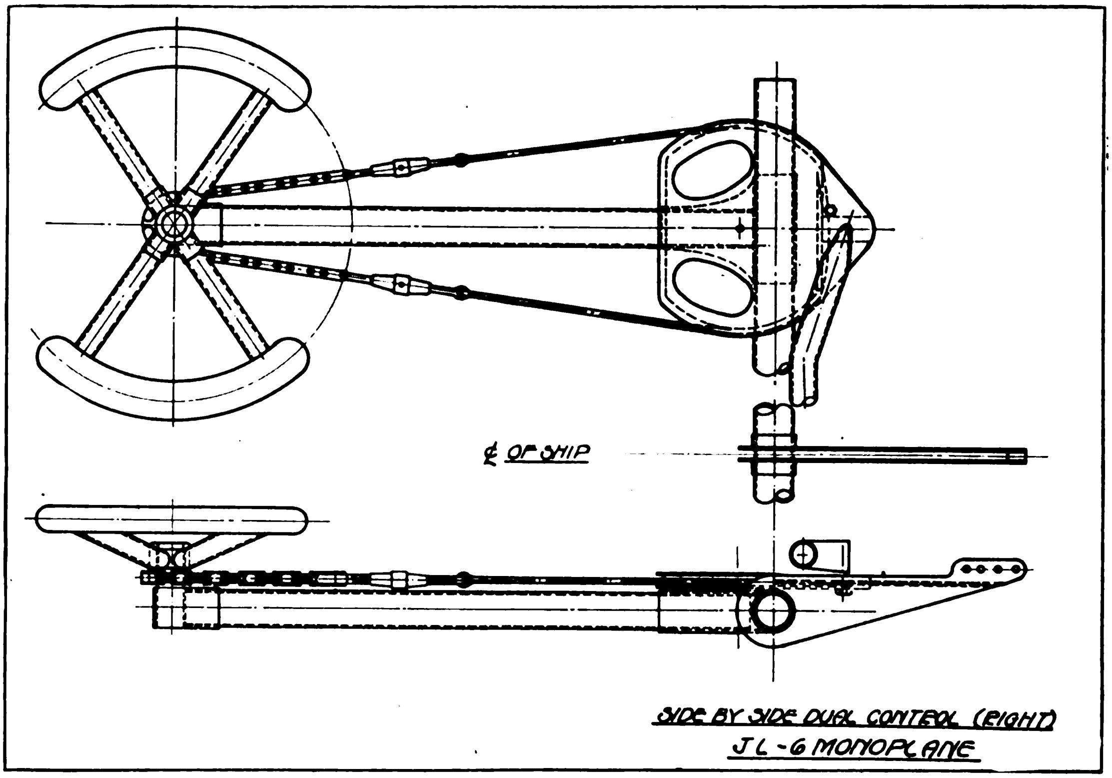


FIG. 34.

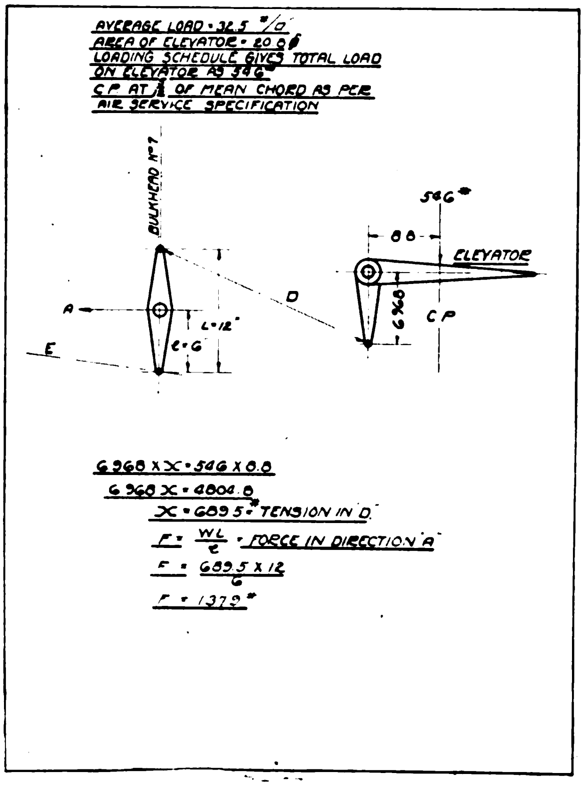
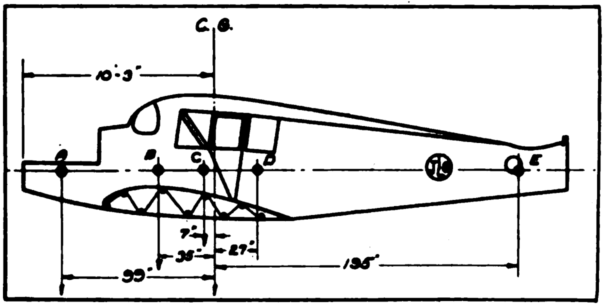


FIG. 35.—Forces causing No. 7 bulkhead failure.

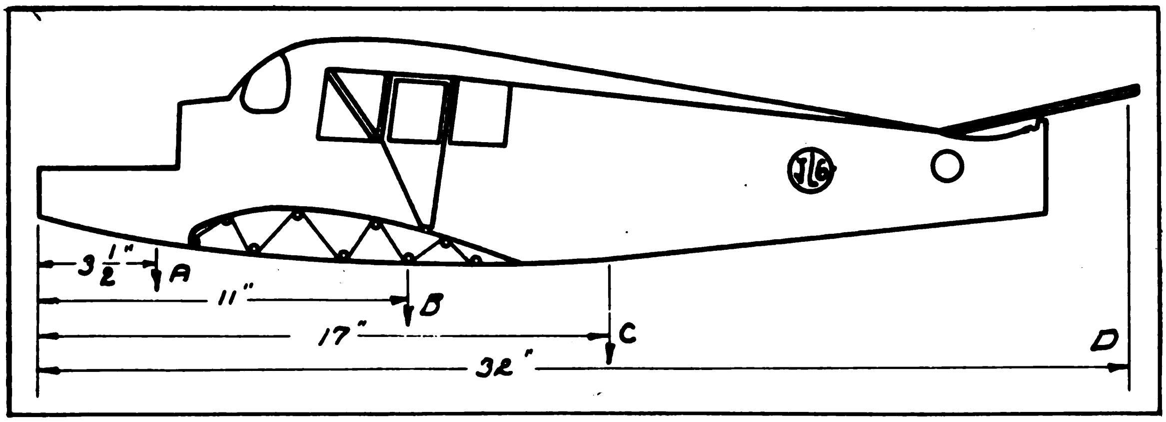


LOADING SCHEDULE AND TOTAL LOADS.

Load factor.	Load, in pounds, at—					Total load.	Remarks.
	A	B	C	D	E		
2	1,588	900	460	700	892	4,480	
2.5	1,985	1,125	625	875	1,115	5,725	
3	2,382	1,350	790	1,050	1,338	6,910	
3.5	2,779	1,575	955	1,225	1,561	8,095	
4	3,176	1,800	1,120	1,400	1,784	9,280	
4.5	3,573	2,025	1,285	1,575	2,007	10,465	
5	3,970	2,250	1,450	1,750	2,230	11,650	Fuselage buckled at seams.
5.5	4,367	2,475	1,615	1,925	2,453	12,835	
6	4,764	2,700	1,780	2,100	2,676	14,020	
6.5	5,161	2,925	1,945	2,275	2,899	15,205	
7	5,558	3,150	2,110	2,450	3,122	16,390	Failure; motor support collapsed.

NOTE.—The forward end collapsed before the jacks were free under the load at (E). After the fuselage was counterbalanced the load was imposed at (E). The next failure occurred aft of bulkhead No. 4.

FIG. 36.



Load factor.	Deflections at—				Remarks.
	A	B	C	D	
2	0.3	0.1	0.1	0.3	
2.5	.3	.2	.2	.6	
3	.7	.4	.4	.7	
3.5	.7	.5	.5	.9	
4	.7	.5	.5	1.0	
4.5	.7	.5	.6	1.1	
5	.8	.5	.7	1.4	Fuselage buckled at seams.
5.5	....	.6	.8	1.6	
6	....	.6	.9	1.7	
6.5	Deflections discontinued.				
7	Failure.				Engine support collapsed.
7.5	Failure.				Rear part of fuselage collapsed.

FIG. 37.

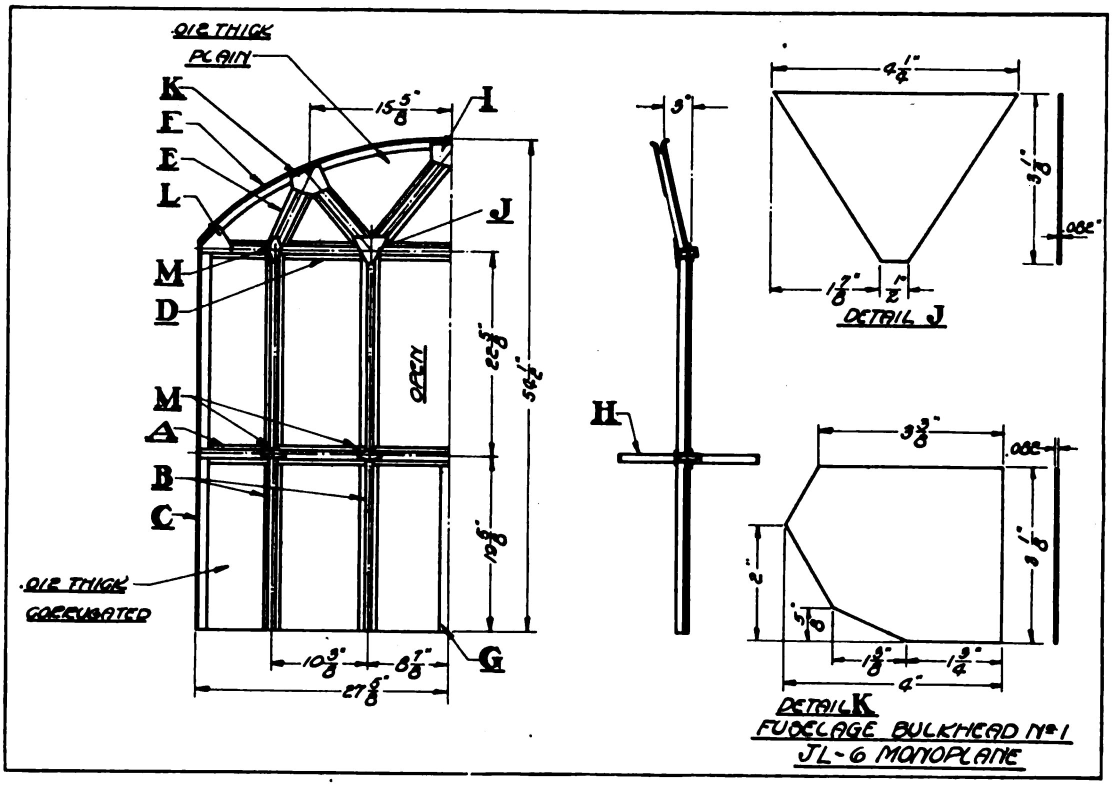

.012 THICK
PLAIN
K
F
E
L
M
D
M
A
B
C
.012 THICK
CORRUGATED
I
J
G
H
OPEN
DETAIL J
DETAIL K
FUSELAGE BULKHEAD Nº 1
JL-6 MONOPLANE

FIG. 38.

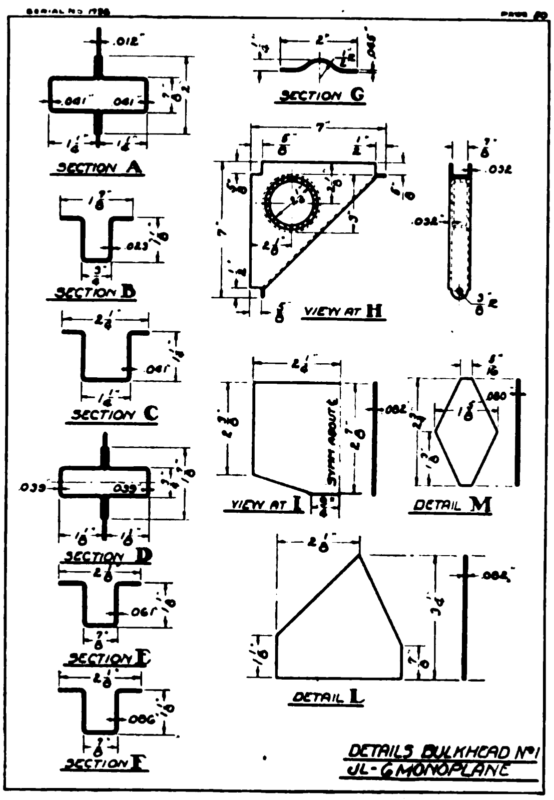

SECTION A
SECTION B
SECTION C
SECTION D
SECTION E
SECTION F
SECTION G
VIEW AT H
VIEW AT I
DETAIL M
DETAIL L
DETAILS BULKHEAD Nº 1
JL-6 MONOPLANE

FIG. 39.

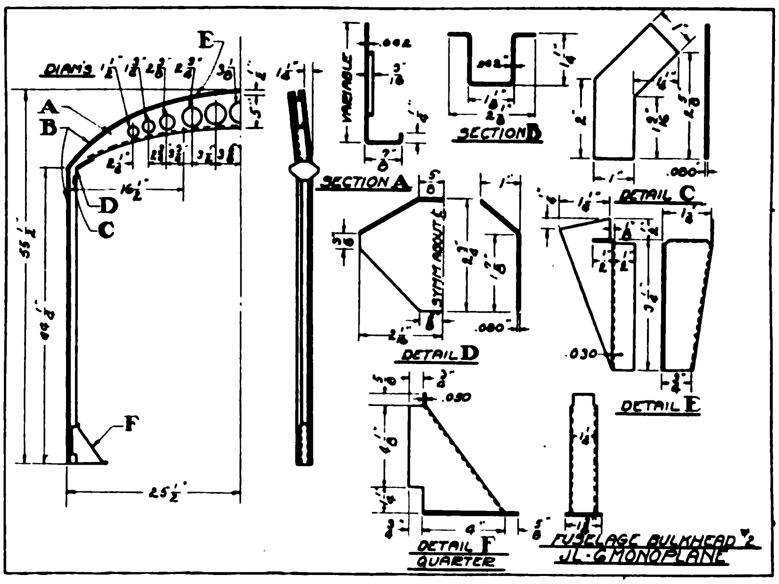

DIAM'S
SECTION A
SECTION B
DETAIL C
DETAIL D
DETAIL E
DETAIL F
QUARTER
VARIABLE
SYMM. ABOUT ℄
FUSELAGE BULKHEAD No 2
JL-6 MONOPLANE

FIG. 40.

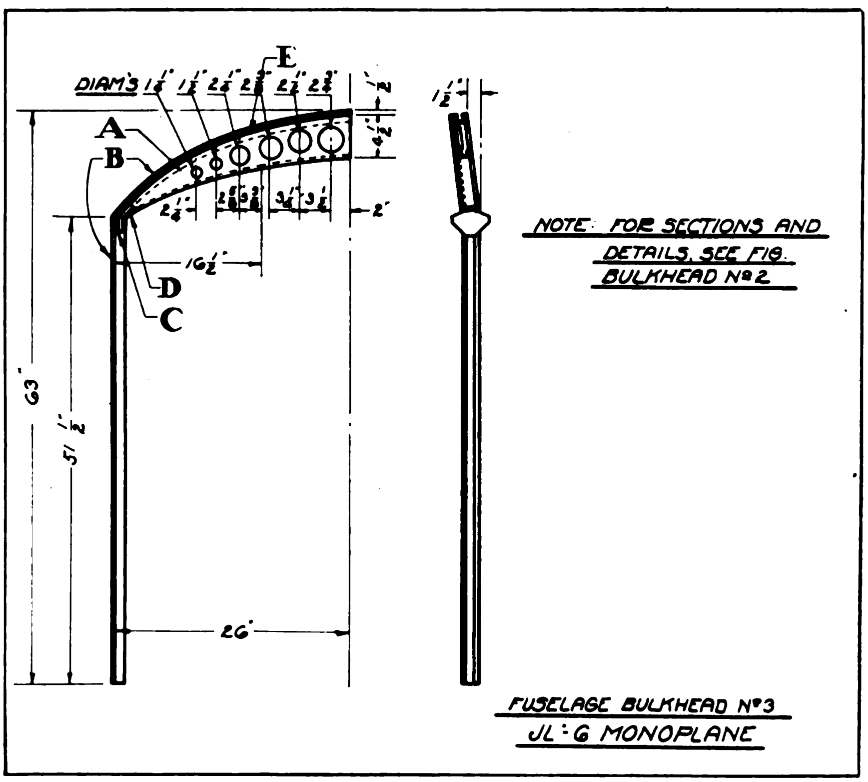

DIAM'S
NOTE: FOR SECTIONS AND
DETAILS, SEE FIG.
BULKHEAD No 2
FUSELAGE BULKHEAD No 3
JL-6 MONOPLANE

FIG. 41.

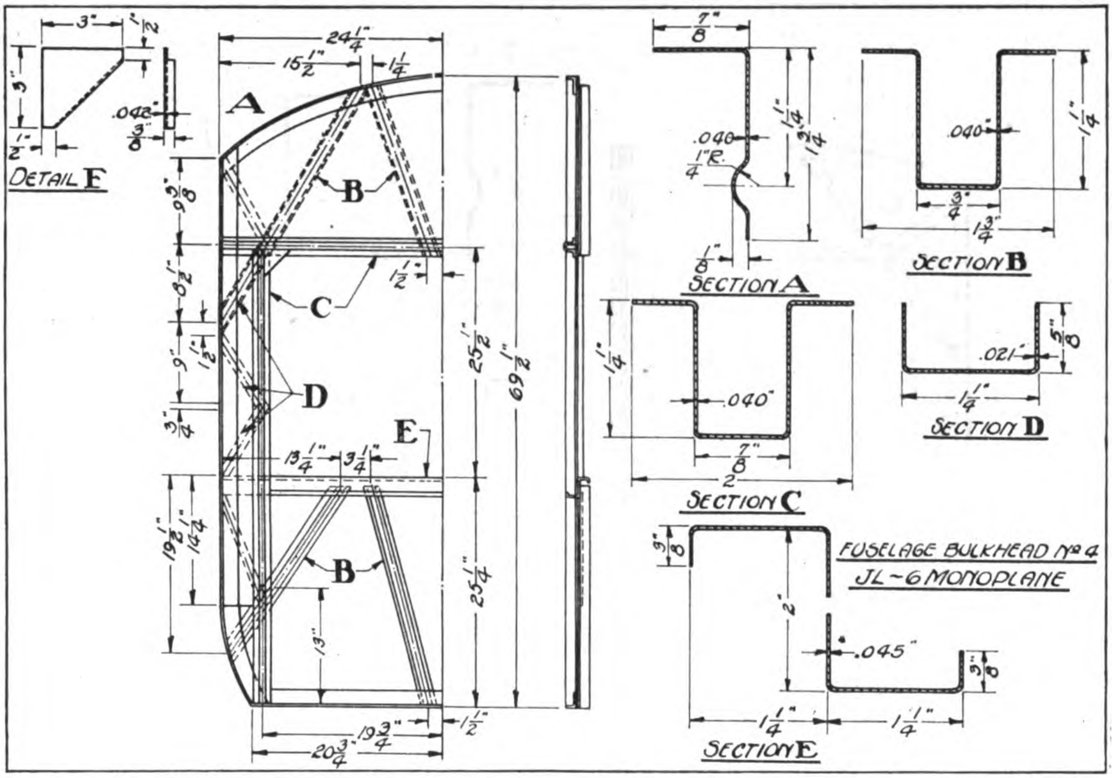

DETAIL E
SECTION A
SECTION B
SECTION C
SECTION D
SECTION E
FUSELAGE BULKHEAD No 4
JL-6 MONOPLANE

FIG. 42.

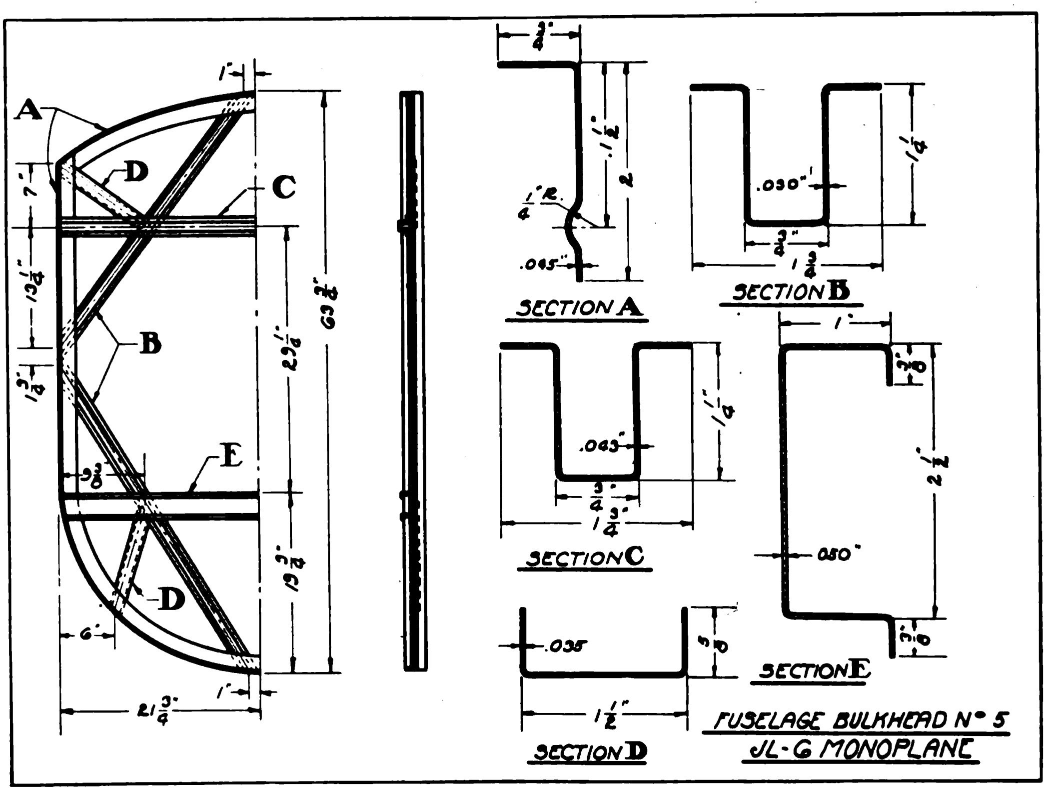

SECTION A
SECTION B
SECTION C
SECTION D
SECTION E
FUSELAGE BULKHEAD N° 5
JL-6 MONOPLANE

FIG. 43.

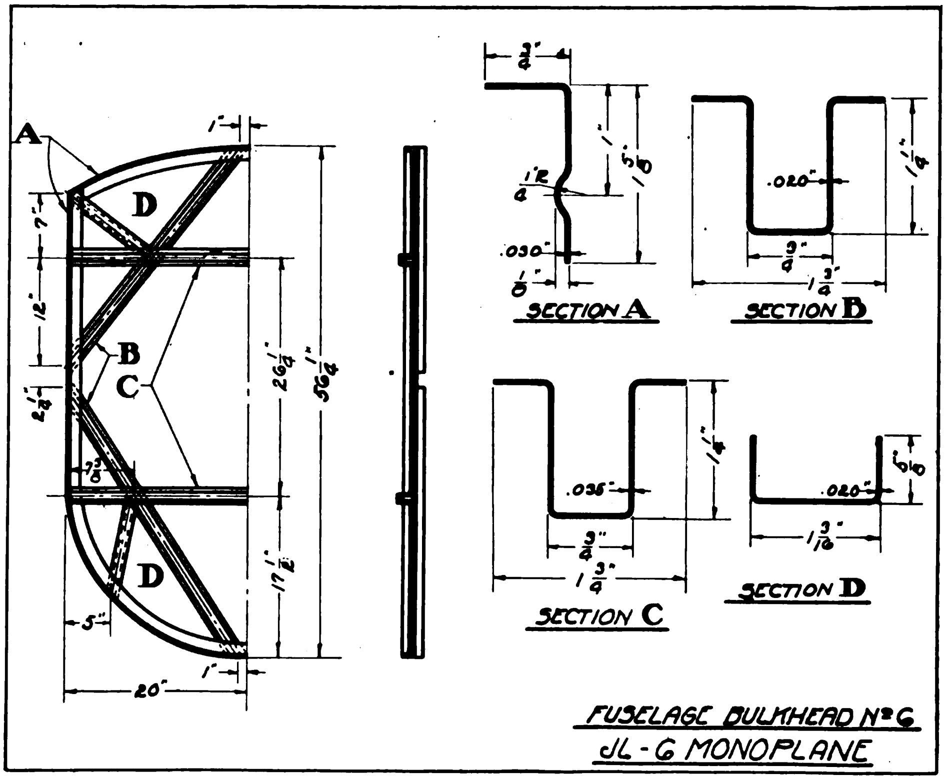

A
B
C
D
D
SECTION A
SECTION B
SECTION C
SECTION D
.030"
.020"
.035"
.020"
20"
5"
FUSELAGE BULKHEAD No 6
JL-6 MONOPLANE

FIG. 44.

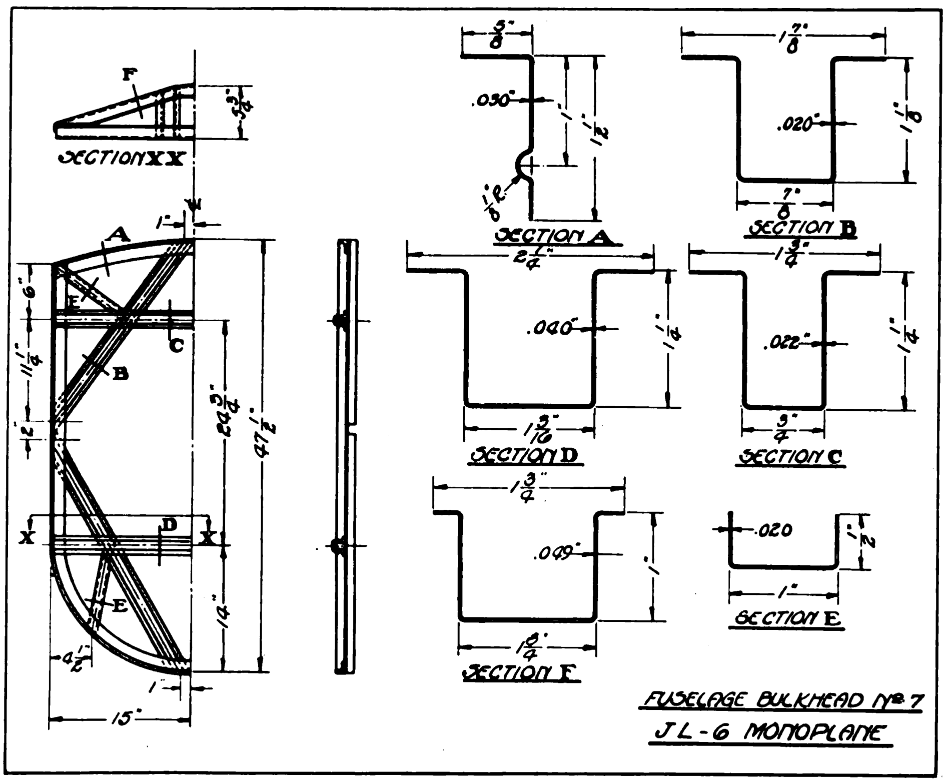

F
SECTION XX
A
B
C
D
E
X
X
15"
SECTION A
SECTION B
SECTION C
SECTION D
SECTION E
SECTION F
.030"
.020"
.040"
.022"
.049"
.020
FUSELAGE BULKHEAD No 7
JL-6 MONOPLANE

FIG 45.

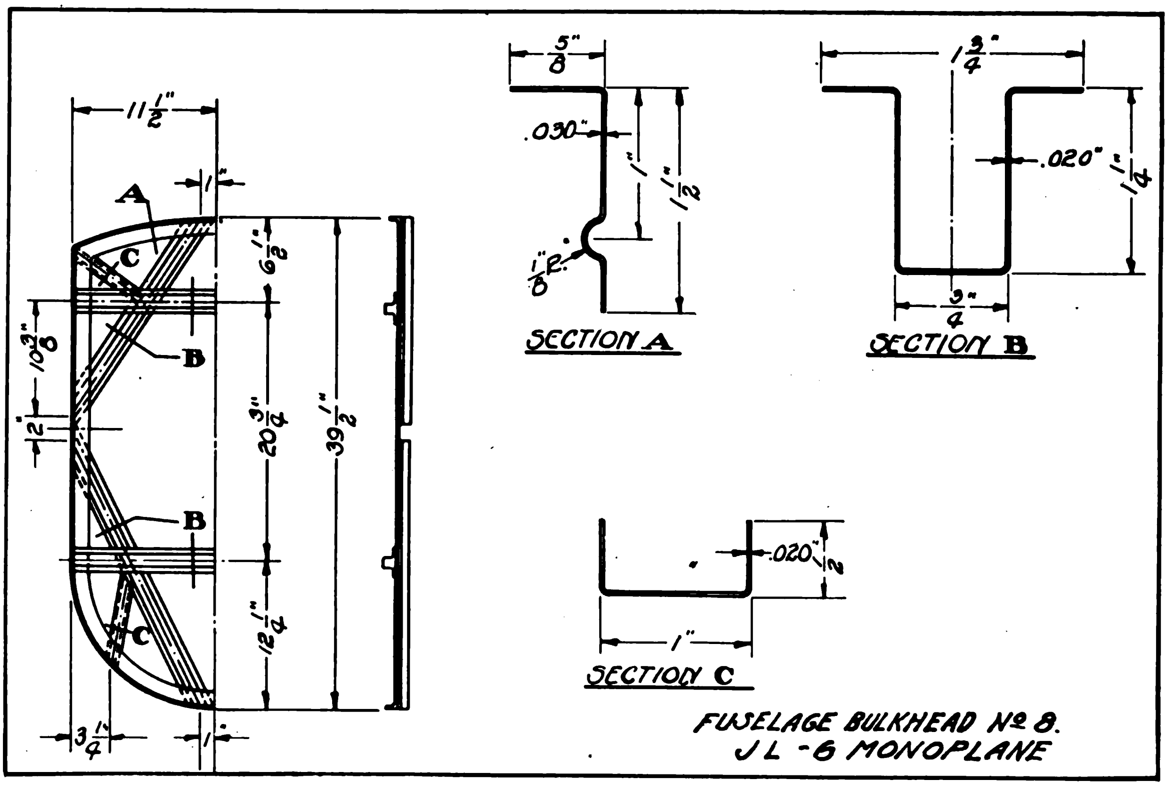

SECTION A
SECTION B
SECTION C
FUSELAGE BULKHEAD Nº 8.
JL-6 MONOPLANE

FIG. 46.

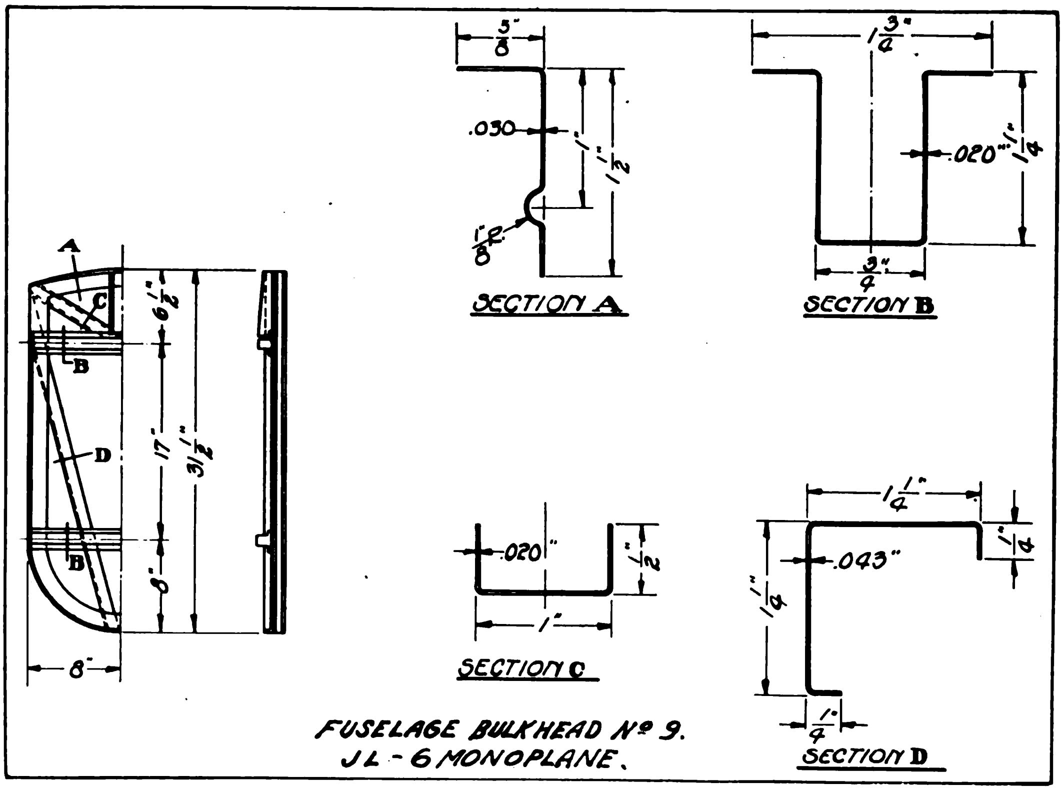

SECTION A
SECTION B
SECTION C
SECTION D
FUSELAGE BULKHEAD Nº 9.
JL-6 MONOPLANE.

FIG. 47.

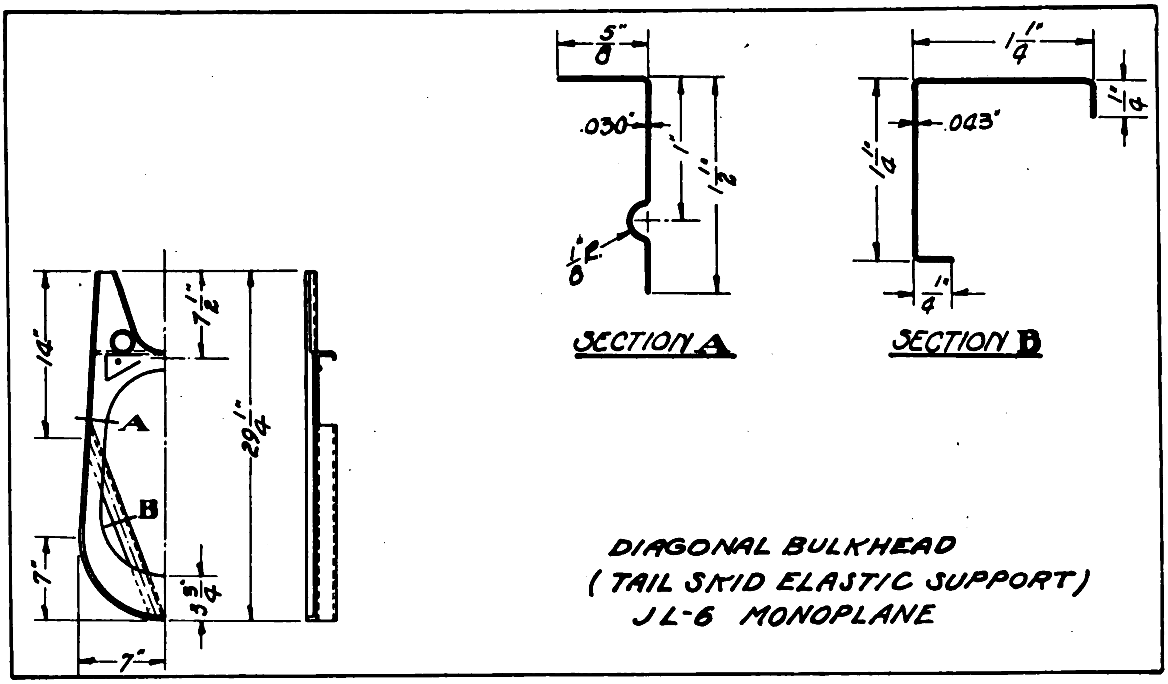

SECTION A
SECTION B
DIAGONAL BULKHEAD
(TAIL SKID ELASTIC SUPPORT)
JL-6 MONOPLANE

FIG. 48.

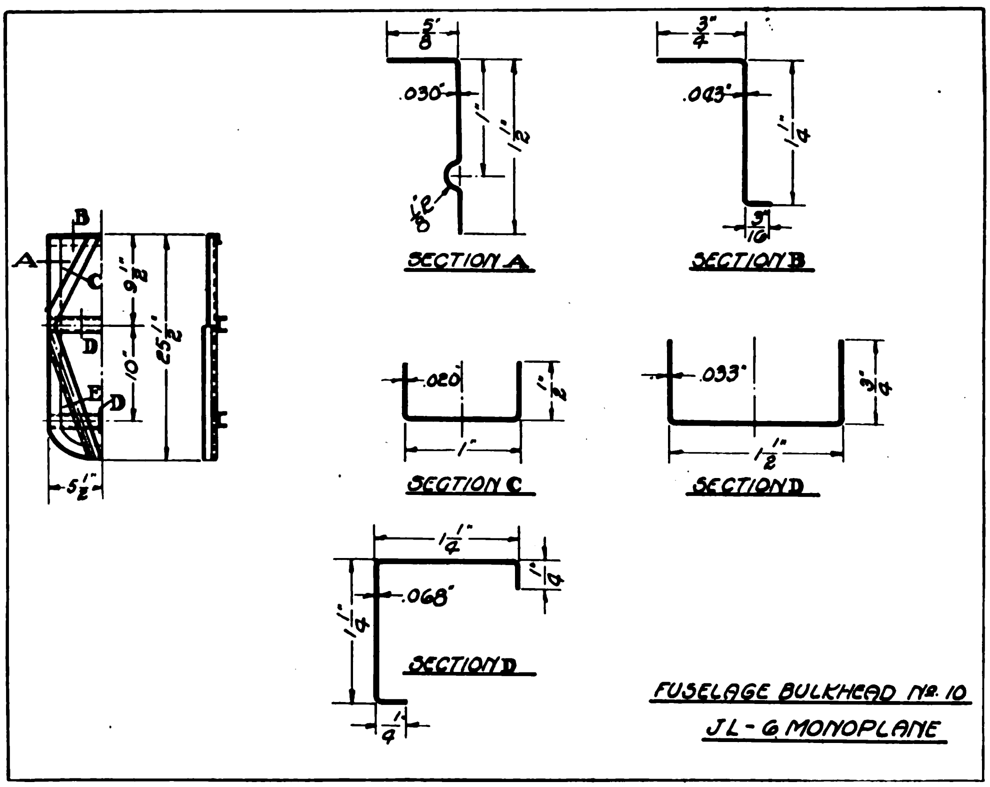

SECTION A
SECTION B
SECTION C
SECTION D
SECTION D
FUSELAGE BULKHEAD No. 10
JL-6 MONOPLANE

FIG. 49.

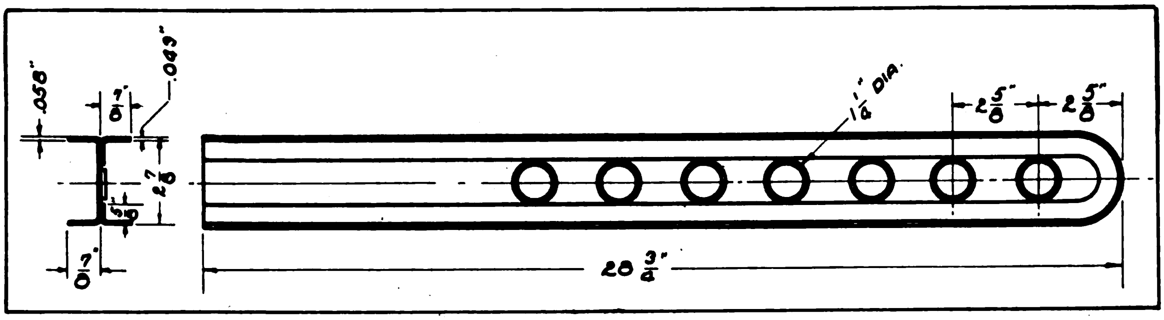


FIG. 50.—Stern post.

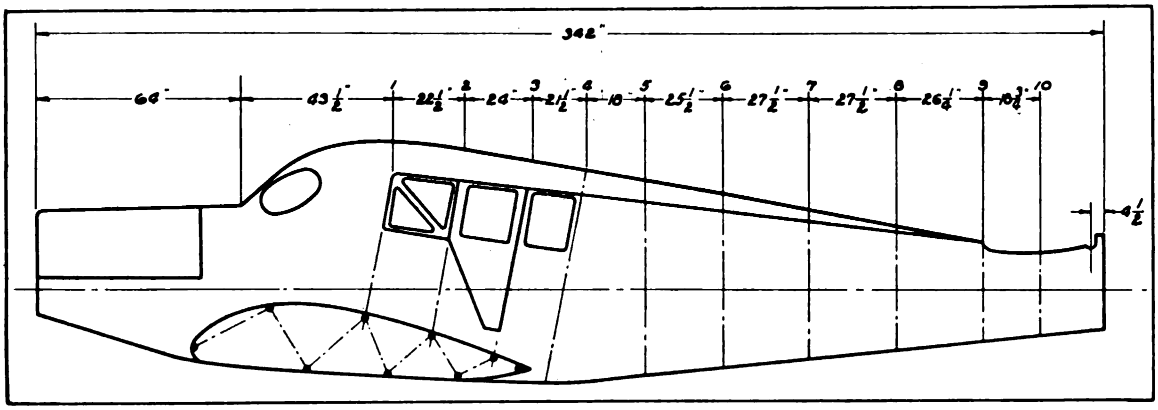


FIG. 51.—Fuselage bulkhead positions.

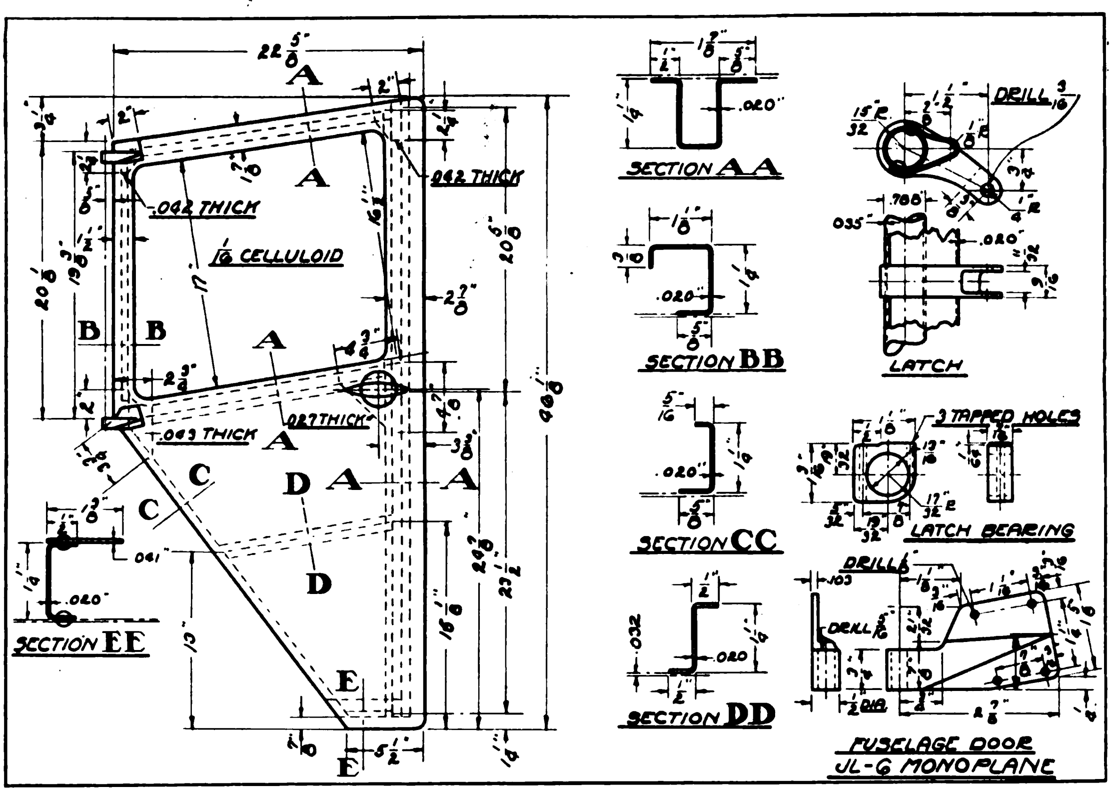


FIG. 52.

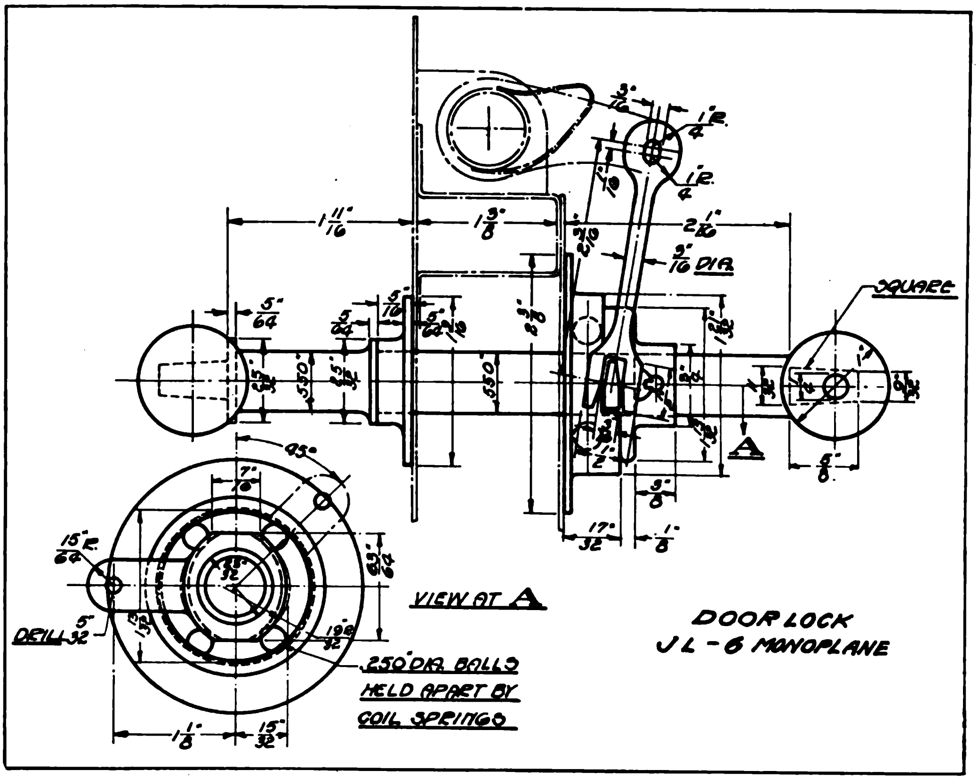

SQUARE
VIEW AT A
DOOR LOCK
J L-6 MONOPLANE
.250 DIA. BALLS
HELD APART BY
COIL SPRINGS
DRILL

Fig. 53.

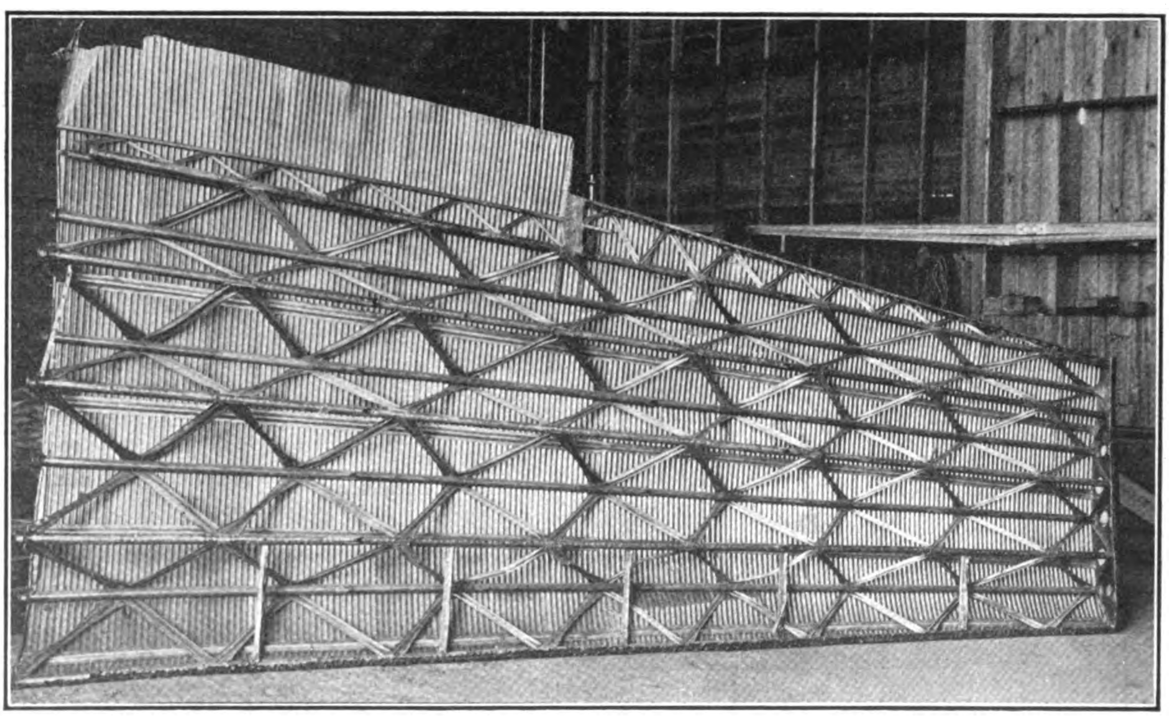


Fig. 54.

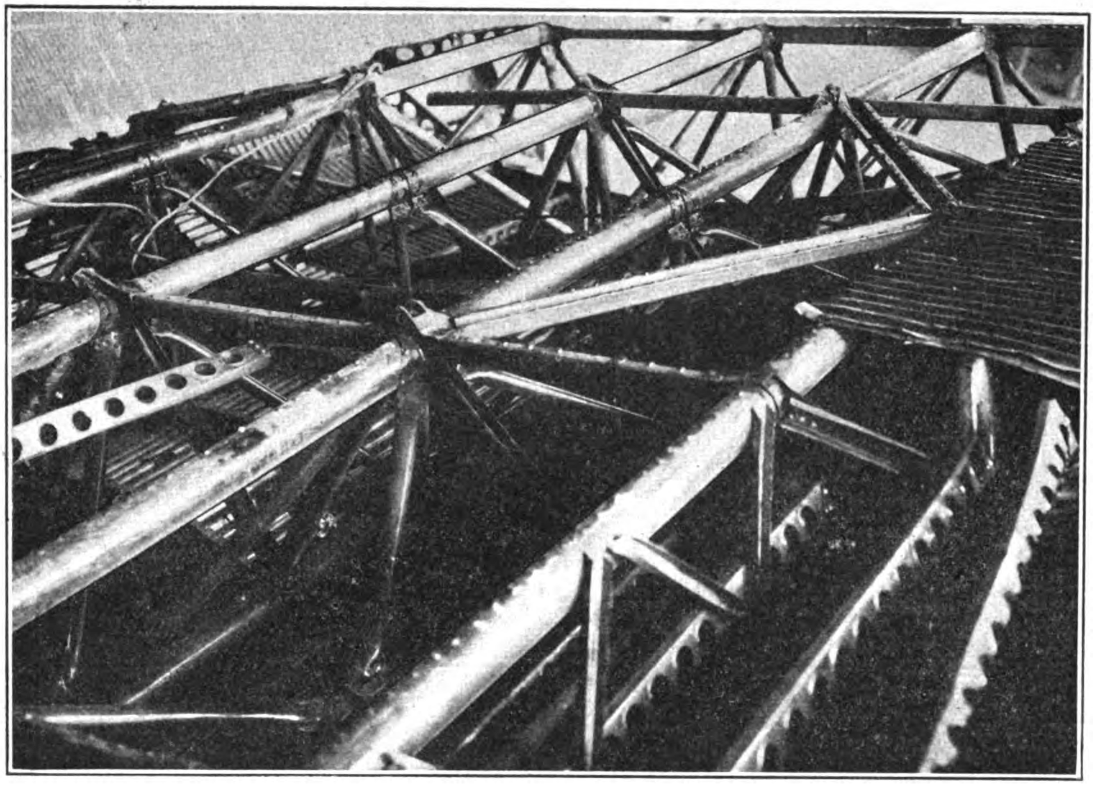


FIG. 55.

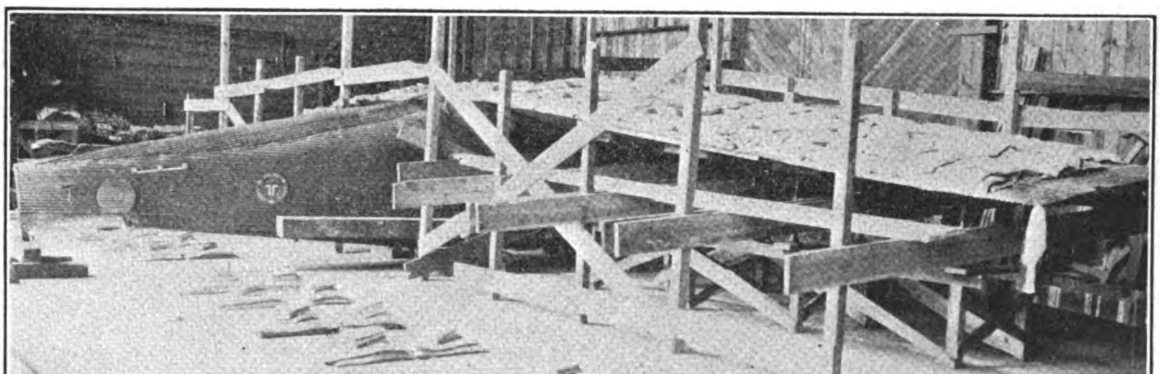


FIG. 56.

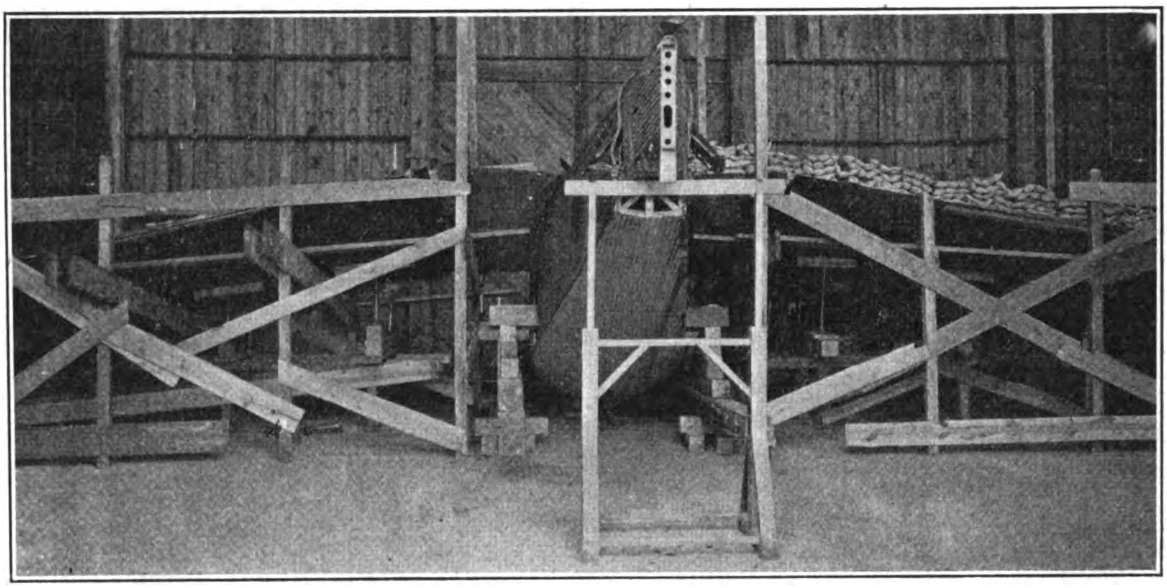


Fig. 57.

Fig. 58.

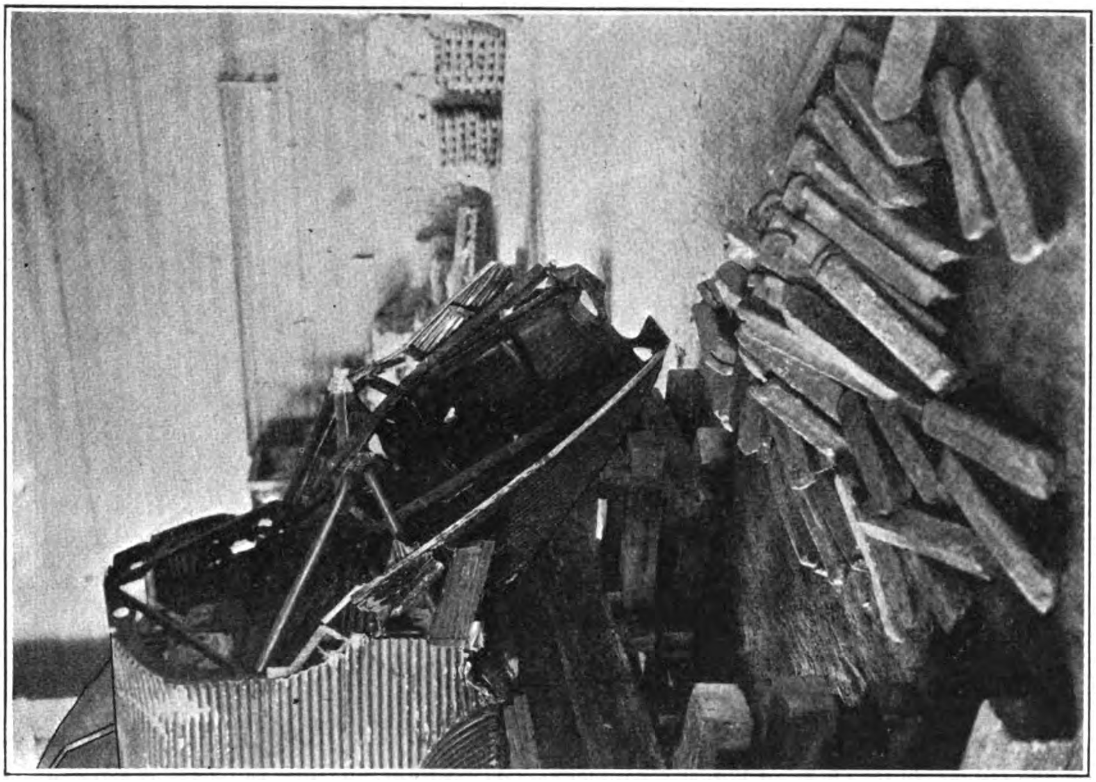


FIG. 59.

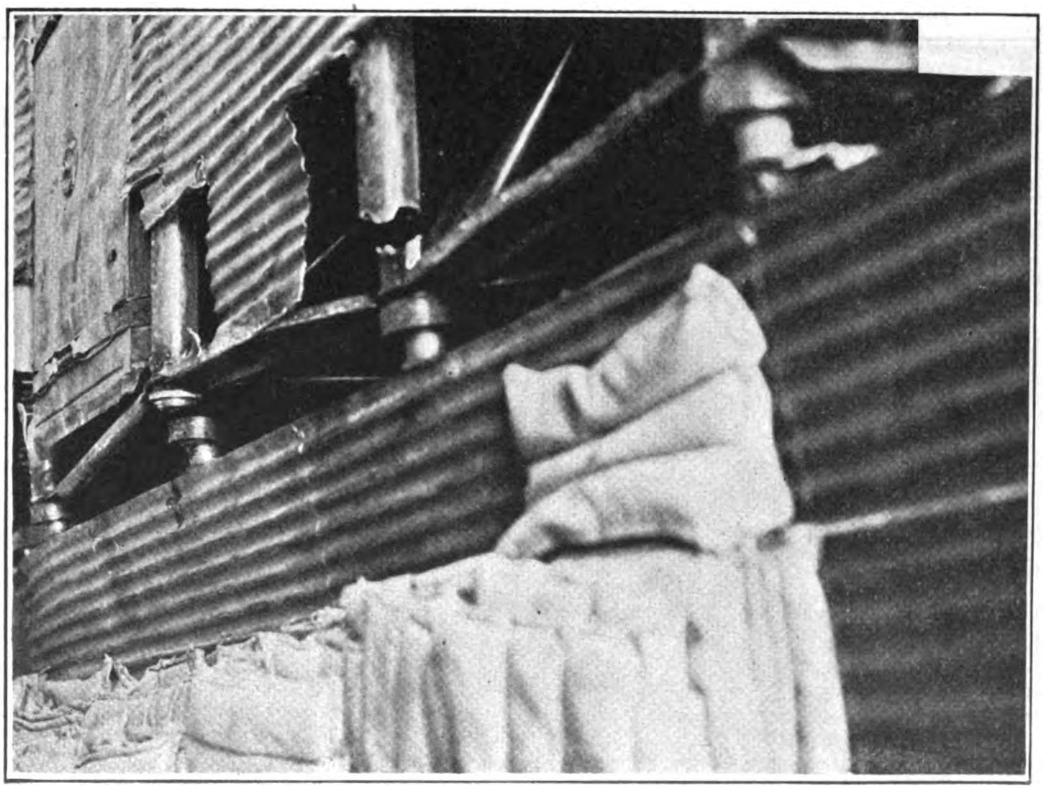


FIG. 60.

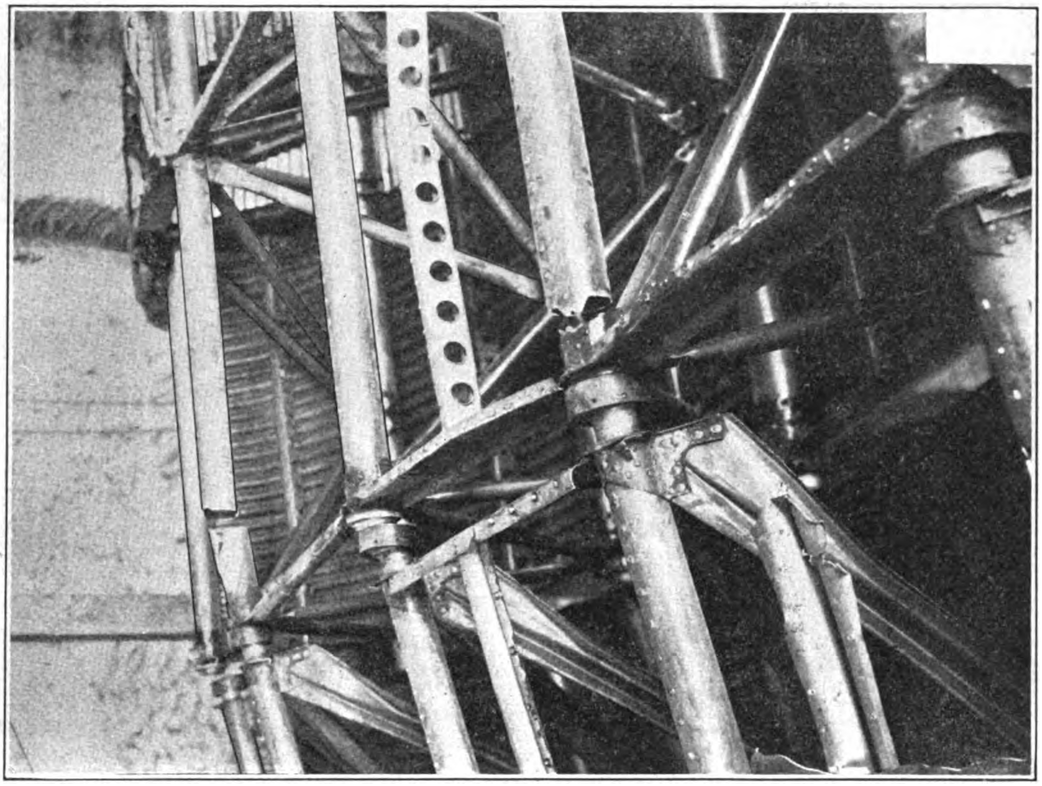


FIG. 61.

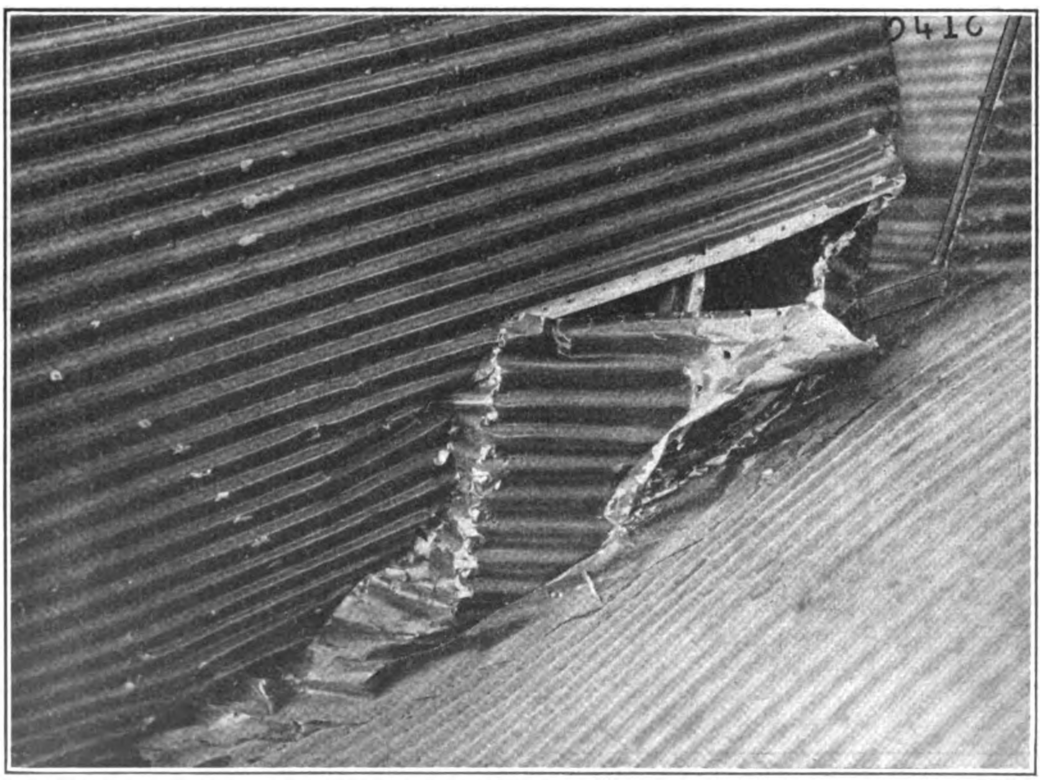


FIG. 62.

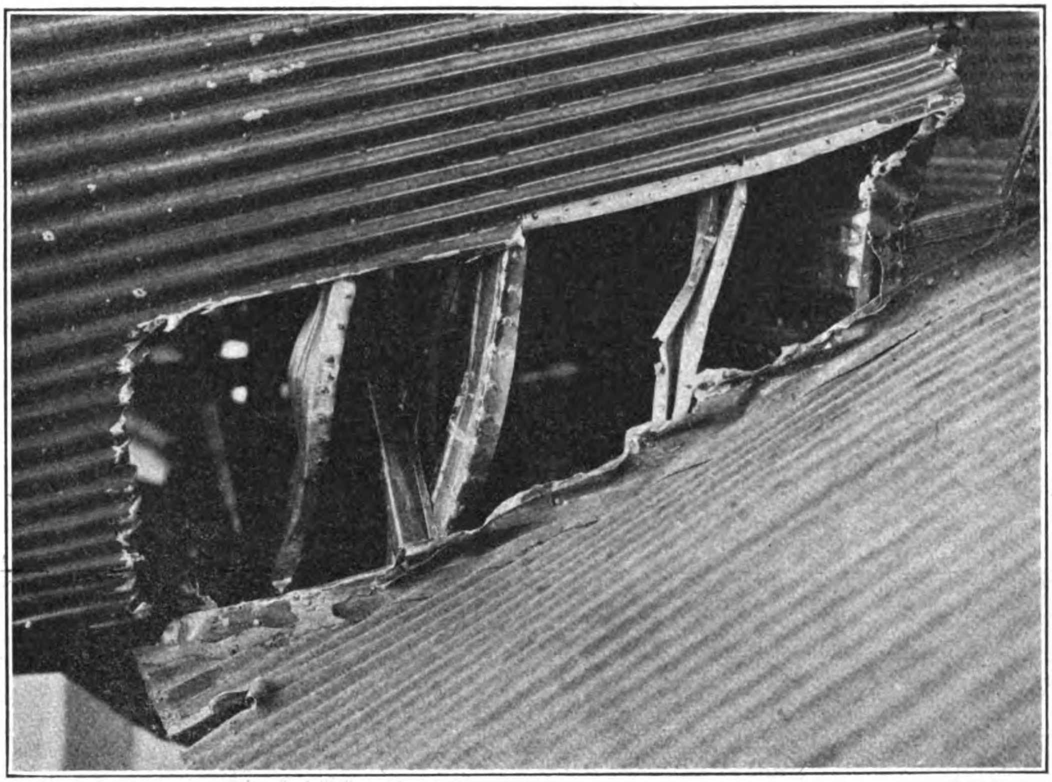
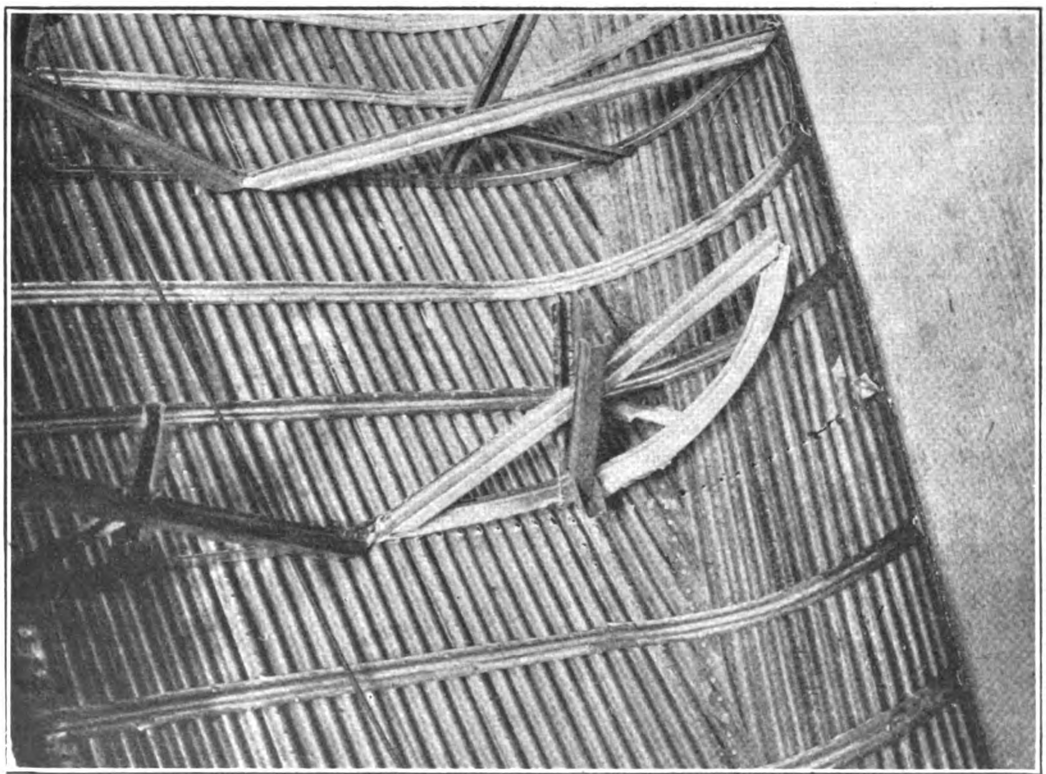


FIG. 63



FI.G 64.

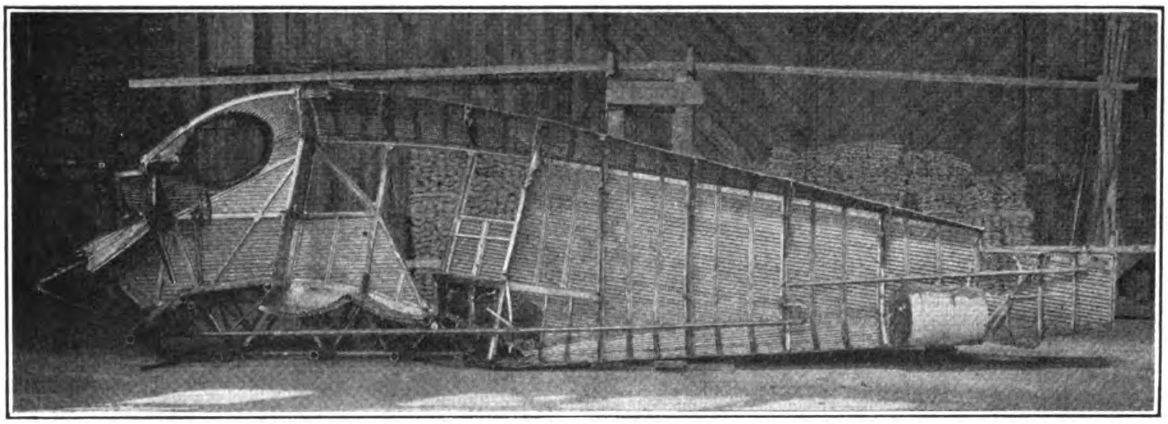


Fig. 65.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

CHANGE No. 1

WAR DEPARTMENT, AIR SERVICE,
May 1, 1925.

Page 10, Figures 7 and 8, Air Service Information Circular, Volume IV, No. 360, "Report of Static Test of the Junker L–6 Monoplane," is corrected by direction of the Chief of Air Service, in accordance with a recommendation of the Engineering Division contained in letter of March 18, 1925, as follows:

Page 10, Figure 7, substitute the following:

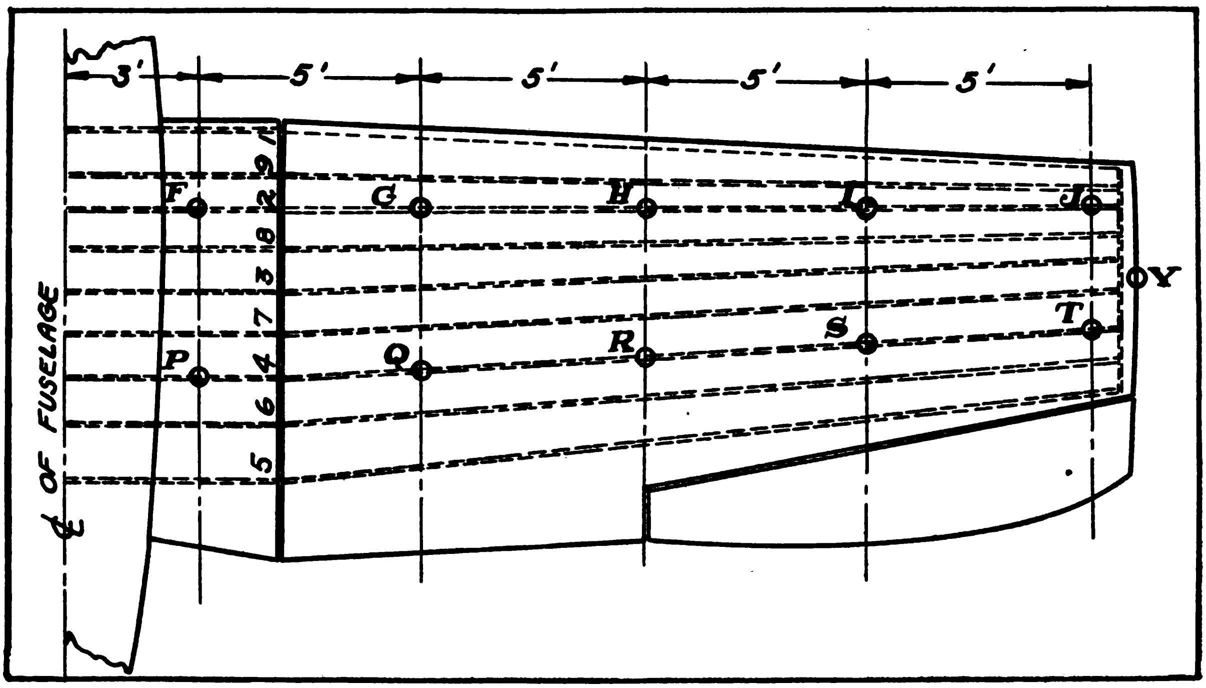
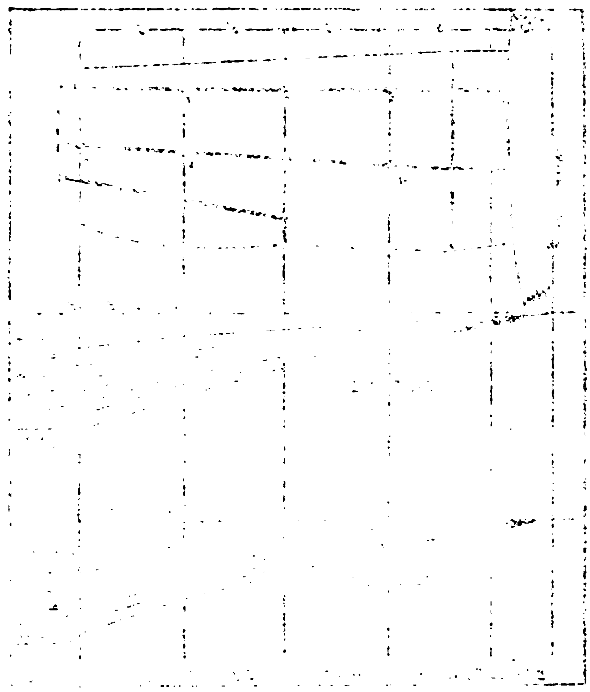


TABLE OF DEFLECTIONS OF RIGHT WING FOR HIGH INCIDENCE

Load factor	Deflections in inches at—										Retreat
	Front spar					Rear spar					
	F	G	H	I	J	P	Q	R	S	T	Point Y
2.0	0.6	1.1	2.0	2.9	4.1	0.3	0.9	1.8	2.9	4.1	+0.8
3.0	.8	1.7	3.1	4.5	6.4	.5	1.6	2.9	4.5	6.4	+1.0
3.5	.9	2.1	3.7	5.5	8.0	.6	1.9	3.5	5.5	7.8	+1.1
4.0	1.1	2.4	4.4	6.4	9.4	.8	2.3	4.1	6.6	9.3	+1.3
4.5	1.2	2.9	5.1	7.5	10.9	1.0	2.6	4.8	7.5	10.7	+1.5
5.0	1.2	3.2	5.8	8.5	12.3	1.2	2.9	5.5	8.4	12.2	+1.8
5.5	1.3	3.5	6.5	9.8	13.9	1.2	3.1	6.3	9.6	13.7	+2.0
6.0	Deflection readings discontinued.										
6.5	Failure.										
7.0											

FIG. 7

46868—25†



Page 10, Figure 8, substitute the following:

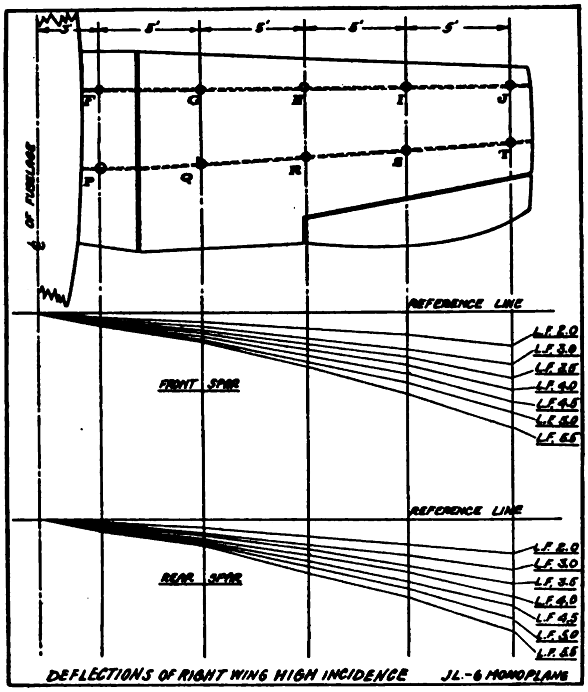


FIG. 8

(C. A. S. I. C. 1)

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1925

McCOOK FIELD REPORT, SERIAL No. 1899

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV — September 15, 1922 — No. 361

CARBURETION, HEAT REJECTION, AND WEIGHT DATA OF U. S. MODEL W-1 ENGINE

(POWER PLANT SECTION)

▽

Prepared by
L. S. Hobbs, A. M. E., Test Engineer
Engineering Division, Air Service
McCook Field, Dayton, Ohio
April 5, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INDEX.

CARBURETION, HEAT REJECTION, AND WEIGHT DATA OF U. S. MODEL W-1 ENGINE.

OBJECT.

The object of this test was to secure a carburetor setting which would give an actual brake horsepower of the United States model W-1 engine of 710 at the normal revolutions per minute of 1,700 with a specific fuel consumption of 0.51 to 0.53 pound per horsepower-hour. Also to secure data on the rejection of heat to the cooling water and the weight of the engine and cooling water.

RESULTS.

The results of this test are given by the included data and curves. Data were secured on several carburetor settings to cover any contingency that may arise when the engine is mounted in an airplane.

CONCLUSIONS.

The results show that it is a characteristic of the carburetors to give a very low specific fuel consumption when throttled on propeller load. With the present air bleed, a carburetor setting which gives a fuel consumption of 0.51 to 0.53 pound per brake horsepower-hour at 1,700 revolutions per minute full throttle, will give a fuel consumption of approximately 0.465 pound per brake horsepower-hour at 1,500 revolutions per minute. It is, therefore, recommended that these carburetors be given a thorough trial in an airplane before the final setting is definitely established. The following setting is recommended for use until actual airplane tests are made: Choke, $1\frac{9}{16}$ inches; main jet, No. 48; air bleed, No. 45.

DESCRIPTION.

This engine is the fourth model "W" engine assembled and is numbered A. S. No. 95012. This engine differs from the original model "W" tested in the following respects: It has a new design, strengthened crank case; new design gear case with ball bearings replacing the orginal bronze; new magneto bracket (see fig. 6) mounting four instead of three magnetos; new intake tubes through the crank case; new breather tubes; new enlarged oil leads to the cam shaft; reworked pistons with enlarged oil grooves; and new type NA-S6 carburetors.

These carburetors are single barrel, single venturi carburetors with the float chamber at the side of the barrel. Their operation is the same as that of all Stromberg models, that is, a common air-bleed jet and accelerating well with a separate idling system which takes its fuel supply from around the accelerating well. The mixture control is obtained on the "auxiliary air port" principle, by means of butterfly valves which admit air to the mixture passage above the venturis, thus "leading out" the mixture. For a detailed description of the principle of operation of this control see Air Service Information Circular, volume 3, No. 292. The accelerating well, discharge nozzle, fuel metering jet, idle tube, and air-bleed metering jet are all removable and can be made any size.

METHOD OF TEST.

The engine was mounted on the dynamometer in the power plant laboratory at McCook Field, Dayton, Ohio. The first dynamometer run was started on January 6, 1922, and the concluding one made on January 23, 1922.

For a detailed description of the method of making runs and taking readings see Engineering Division report, serial No. 1507.

A run was first made to determine the horsepower and specfic fuel consumption with the setting that was then in the carburetors on the engine. This setting was: Choke, $1\frac{5}{8}$ inches; main jet, No. 46; and air bleed, No. 45. Since the horsepower will show a slight variation with a change in specific fuel consumption, a metering jet size was determined which gave the normal fuel consumption (0. 510 to 0.530 pound per brake horsepower per hour at full-throttle normal speed). The engine was then throttled to give the desired brake horsepower (710) at normal speed and the manifold vacuum recorded. From the relation of this vacuum to that at full-throttle normal speed a choke size was calculated to give the required horsepower without throttling and verified by test. A metering jet size was then determined to be used in conjunction with this choke, which gave the desired specific fuel consumption at full throttle. (See fig. 14.)

A standard carburetion run was then made (see pp. 34 and 35 of report, serial No. 1507 mentioned above), the results of which are shown on the datum sheets (series A) and curve sheets. As will be noticed from the corresponding curve, figure 14, the specific fuel consumption has a decided tendency to drop when the engine is throttled on propeller load. It was, therefore, decided to obtain data on the carburetor characteristics when using larger metering orifices so these data (series A) would be available in case it was found necessary to resort to richer settings when the engine was in an airplane. The extent of the tendency of the fuel consumption to drop when the throttle is closed can be regulated somewhat by varying the size of the air-bleed orifice. This was done and different combinations of fuel-metering orifice with air-bleed orifice were tried and the data (series B and C) recorded. (See pp. 15 and 16.)

The regular carburetor head-test runs were made and the data (series D) are given on page 16 (Subsequent to the completion of this test it was decided to obtain the head at which the carburetors would flood, both with the engine running and not running. The engine used throughout this test at the time this decision was reached had been removed from the dynamometer but a duplicate

was available at the torque stand in engine A. S. No. 94626. This engine was equipped with NA-S6B carburetors (single venturi, float chamber depression mixture control). These carburetors have similar floats and float arms and the same area of needle valve and seat as the NA-S6 carburetors used on engine A. S. No. 95012. On March 7, 1922, the test was made on these carburetors, the data (series E) from which are given on page 16.

On completion of the carburetion runs while the engine was still on the dynamometer, a set of runs was made to obtain the cooling-water data. These runs were standard full-power runs at speeds of 1,600, 1,700, and 1,800 revolutions per minute, readings of water flow through the engine being taken in addition to the standard readings. The water flow was determined by means of water venturis which had previously been calibrated and the heat data are figured from temperatures which were read with thermometers in the cooling-water line. These thermometers had been previously calibrated and were placed in the cooling-water line with the bulbs in direct contact with the passing water. Complete data (series F) from the cooling-water runs are given on page 17.

At the completion of the various runs the engine was removed from the dynamometer and the weight obtained, together with the weight of the cooling water necessary to fill the cooling spaces in the engine.

Following this a complete set of photographs of the assembled engine was made.

The calibration of the water venturis showed that within the limits of accuracy of the readings, the two venturis were practically identical in flow and that, when used together in parallel, the calibration curves of the individual venturis still held true. The water-temperature thermometers were placed as close to the engine as possible, one in the water inlet and the other in the outlet.

The weight data given in the next column are self-explanatory.

For convenience in reference, the data from the various runs are segregated serially as follows:

- Series A: Carburetor runs with No. 45 air bleed, different size fuel-metering jets.
- Series B: Carburetor runs with No. 38 air bleed.
- Series C: Carburetor runs with unrestricted air bleed, different size fuel-metering jets.
- Series D: Carburetor head-test runs made on dynamometer.
- Series E: Carburetor head-test runs made on torque stand.
- Series F: Heat rejection to cooling-water runs.

ANALYSIS.

Examination of the data shows that in horsepower and fuel consumption this engine is sensitive to air-temperature changes. This was very noticeable during the test. The average air temperature for the majority of these runs lies between 20° and 40° F. These temperatures are considerably below the average of operation, especially on the dynamometer. Therefore, the readings of specific fuel consumption as given throughout this report will probably be considerably increased if the engine is run at a normal air temperature of 60°. It will also be noticed that the brake horsepower is high with the lower temperatures, and this will also be affected and drop when the engine is run under a normal intake air temperature.

The carburetors, as far as could be determined on the dynamometer stand, give smooth running on propeller load at all speeds with all settings from idling (200 to 300 revolutions per minute) to full throttle. As will be seen from an examination of the data, the operation of the air-port type of mixture control tends not only to reduce the actual fuel flow. but also to increase the horsepower by increasing the volumetric efficiency. This condition previously had been observed on other tests of the air-port type of control.

In analyzing the results of the flooding test of the carburetors, conducted at the torque stand (see series E data, p. 16) it should be remembered that in these carburetors the idle system secures its fuel supply from around the accelerating well after the fuel has passed through the main metering orifice. The flooding of these carburetors takes place when the level in the well reaches the height of the outlet passages in the discharge nozzle. The action of the idle drawing on this fuel will have the effect of lowering the fuel level in the well. The extent of this effect is not known and it is problematical as to how much of the marked increase in head necessary to flood the carburetors with the engine running at idling speed is due to this and how much, if any, is due to the better seating of the needle valve due to the vibration.

As noted previously, the cruising-speed specific fuel consumption of this engine is good, With the No. 49 metering orifice and No. 45 air bleed (fig. 16) the specific fuel consumption at 1,500 revolutions per minute is 0.450 pound per horsepower hour. It is doubtful if the engine when mounted in an airplane will run smoothly under all weather conditions on a mixture ratio lean enough to give this consumption. The curves (from series C) on the bottom of figure 16 look to be better probably than the ones (from series A) with the smaller air bleed. Only a trial in the air will determine this, but the cruising-speed fuel consumption of this engine should be well below 0.500 pound per horsepower hour, and this is considered a good rate of consumption. It is believed that enough data are here included to provide for any setting required when the engine is mounted in an airplane.

WEIGHT DATA OF MODEL W-1 ENGINE.

[Date, Jan. 25, 1922.]

		Pounds.
Gross weight of engine as weighed (includes weight of water, some undrained oil and supporting tackle)		1,932
Weight of undrained oil	13.5	
Weight of supporting tackle	24.0	
Total		37.5
Net weight of engine and cooling water		1,894.5
Weight of cooling water necessary to fill engine		80.0
Net weight of engine[1] dry		1,814.5

[1] This engine was weighed after completion of the test and undoubtedly was heavier by a few pounds than a clean engine from the assembly shop would be.

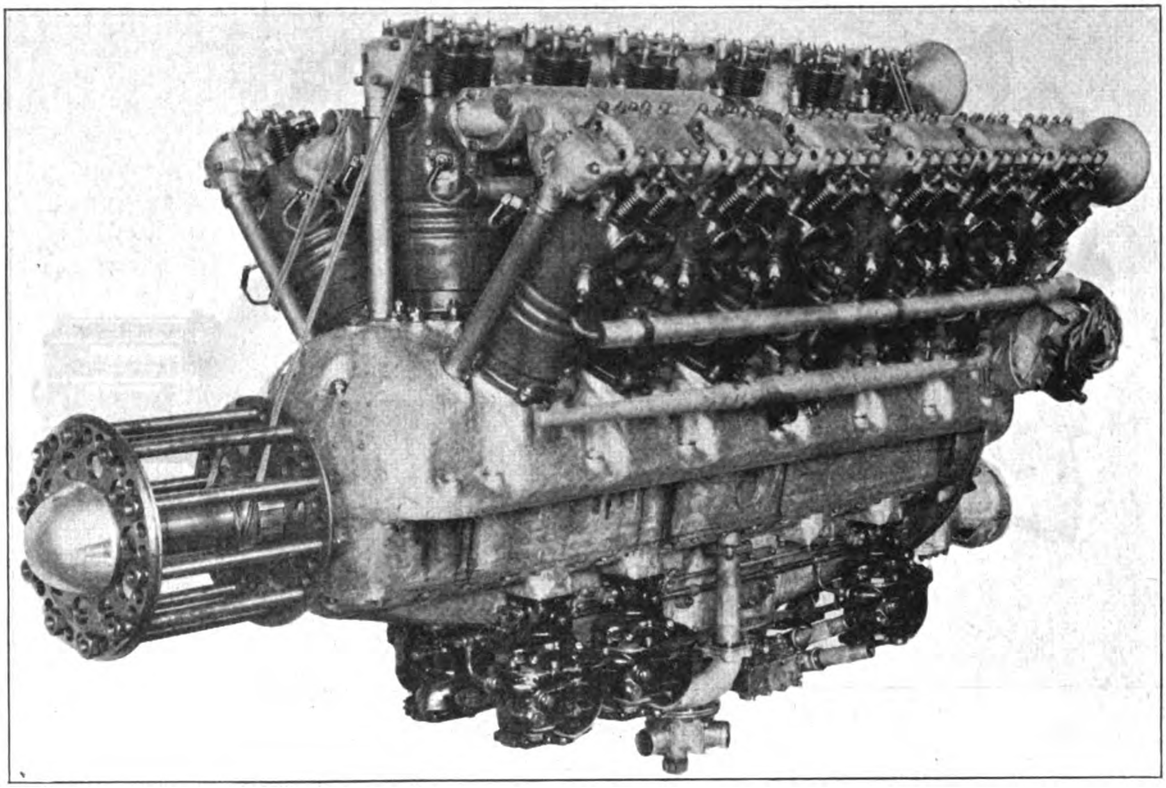


FIG. 1.—Three-quarter front view (left side).

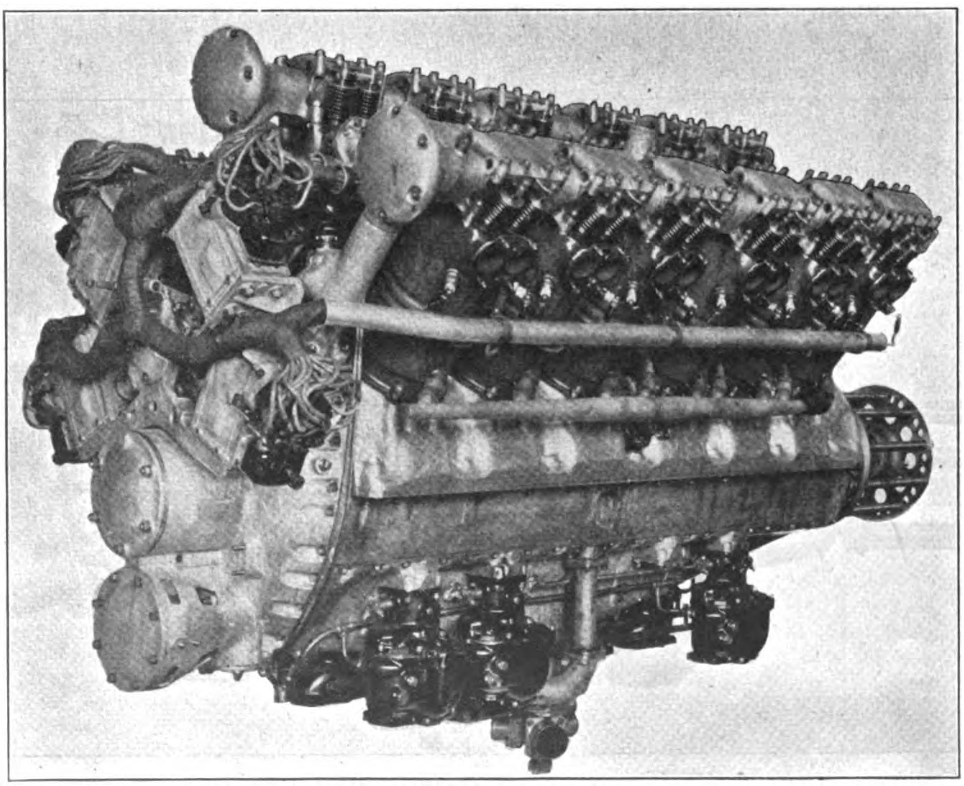


FIG. 2.—Three-quarter rear view (right side).

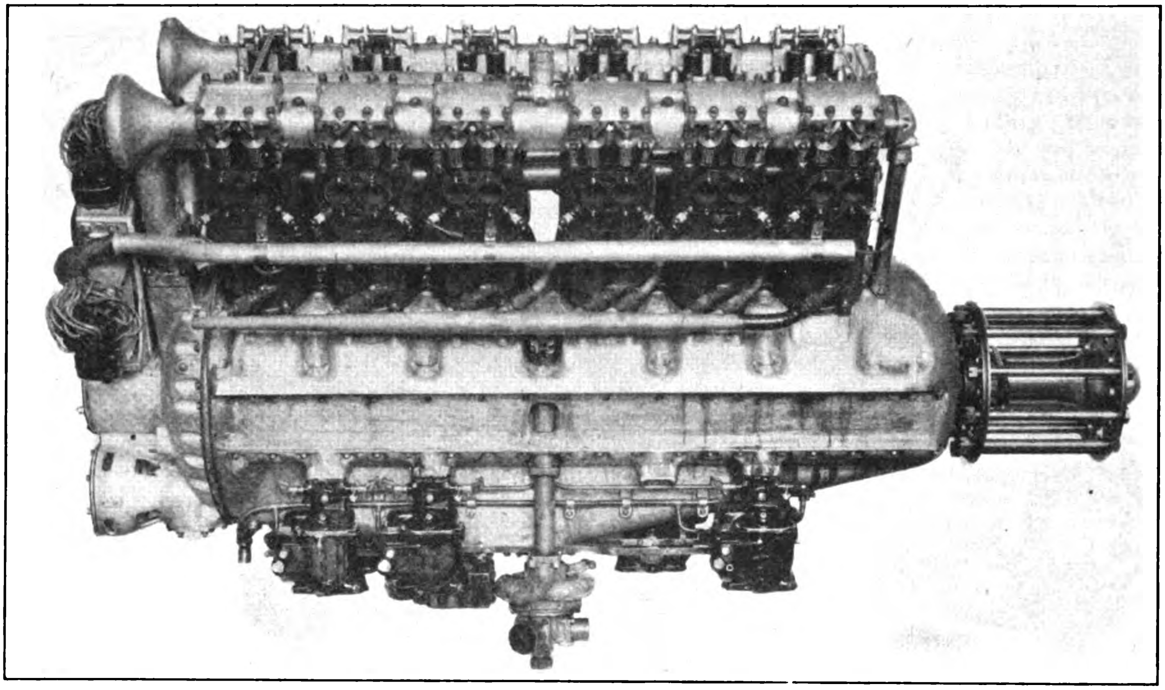


FIG. 3.—Right side view.

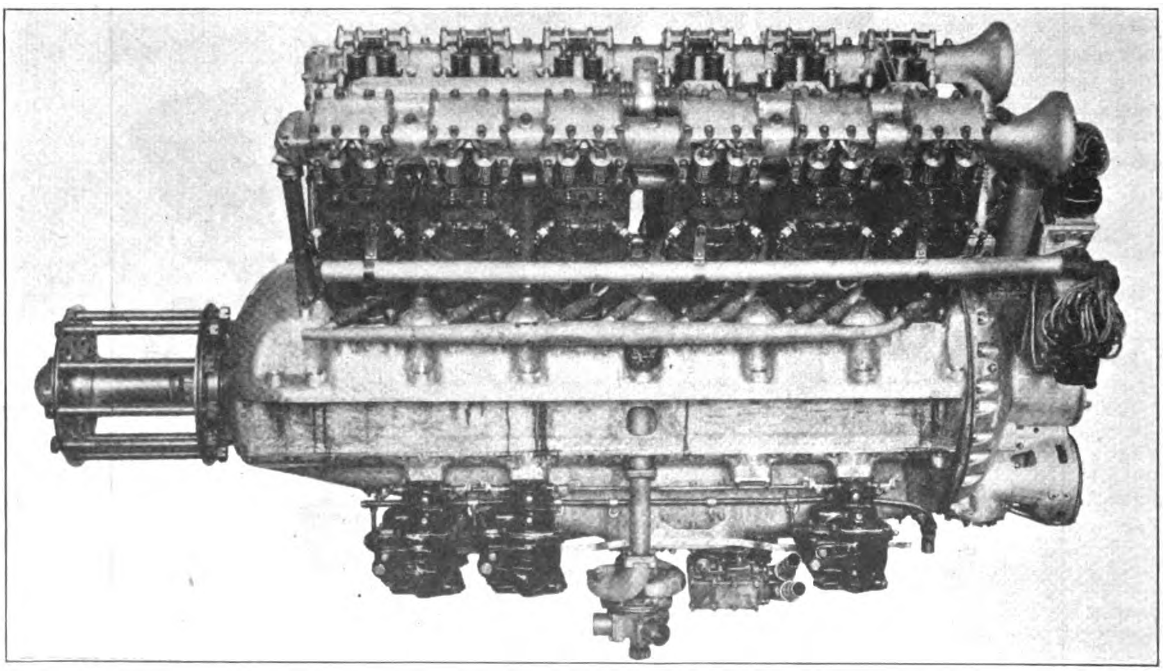


FIG. 4.—Left side view.

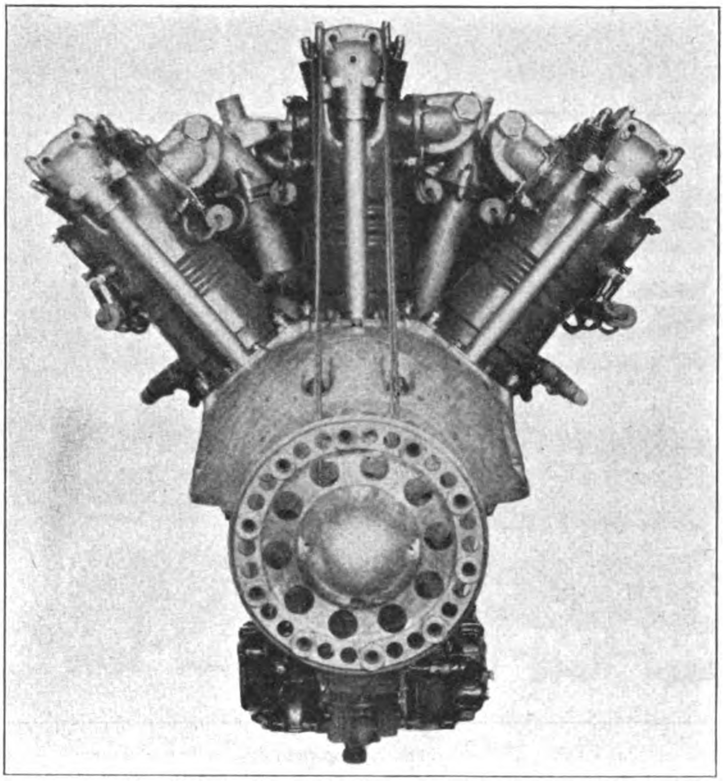


FIG. 5.—Front end view.

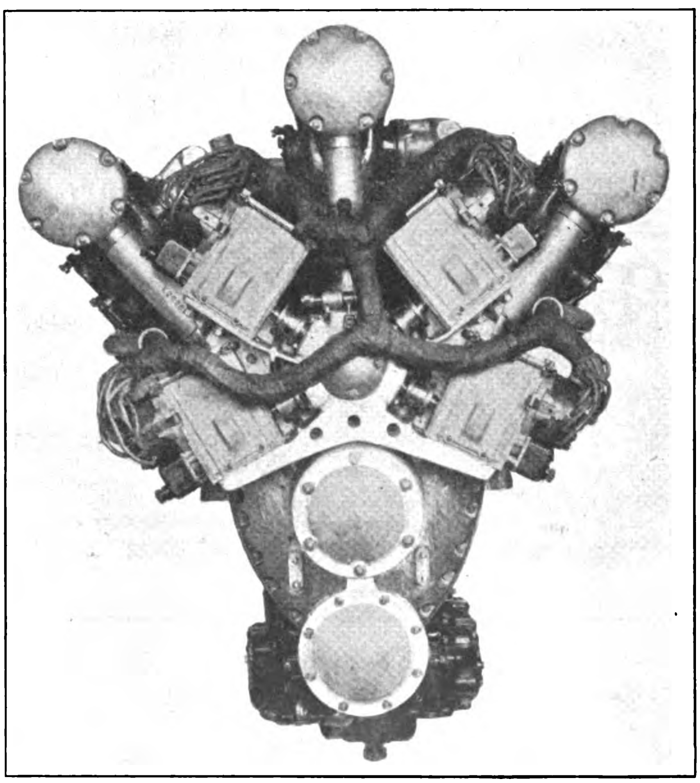


FIG. 6.—Rear end view.

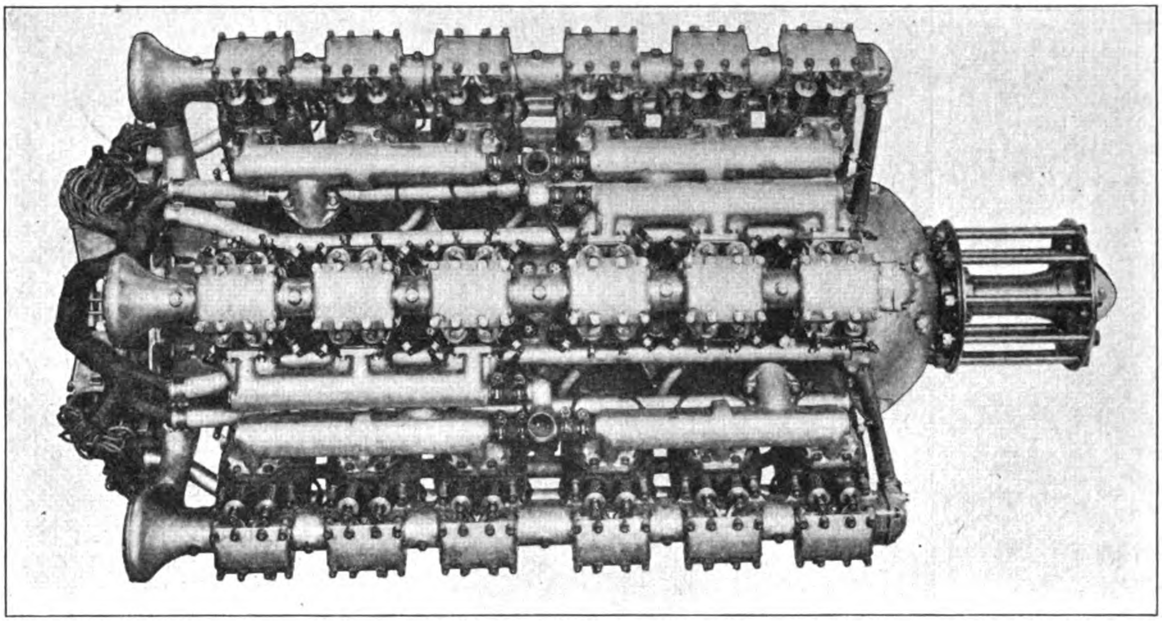


FIG. 7.—Top view.

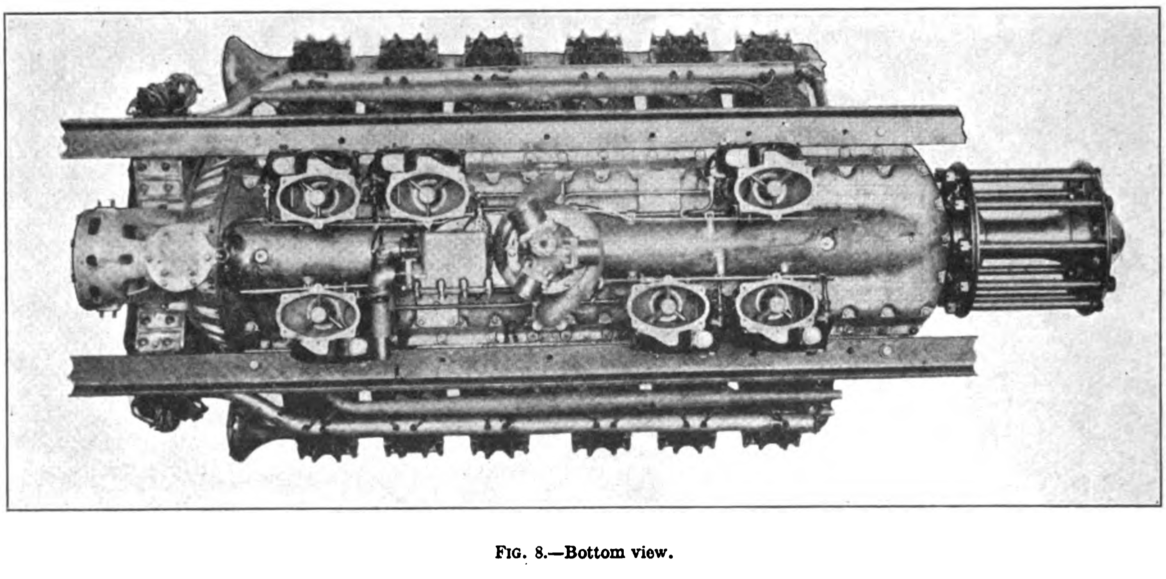


FIG. 8.—Bottom view.

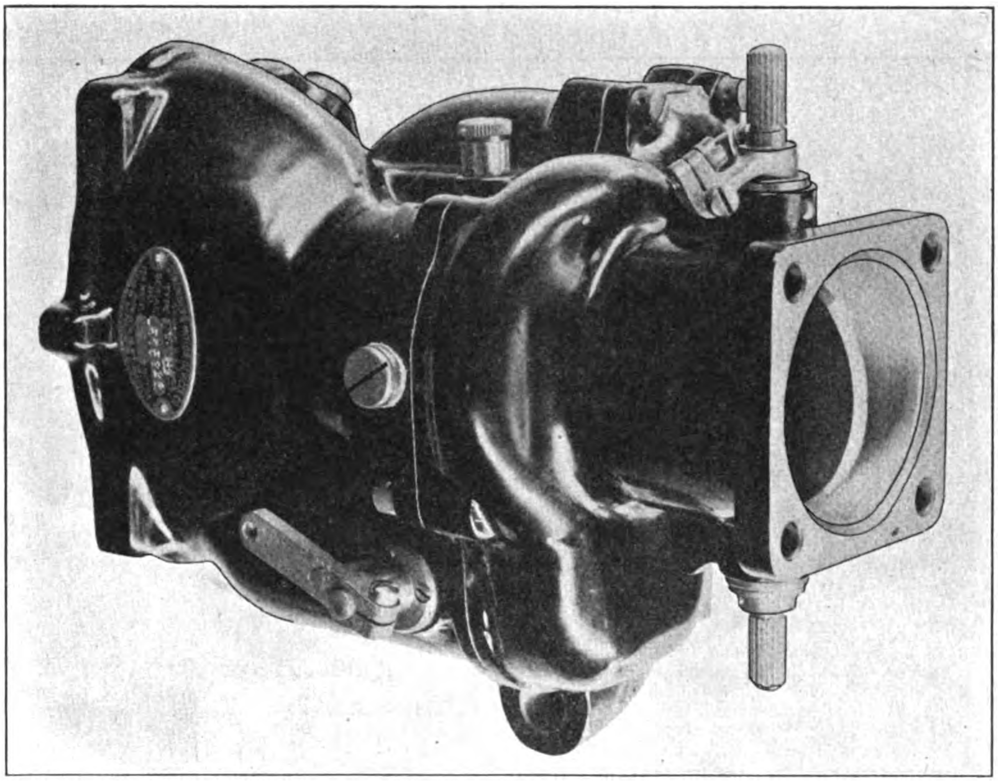


FIG. 9.—Stromberg NA-S6 carburetor. Side (air scoop) view.

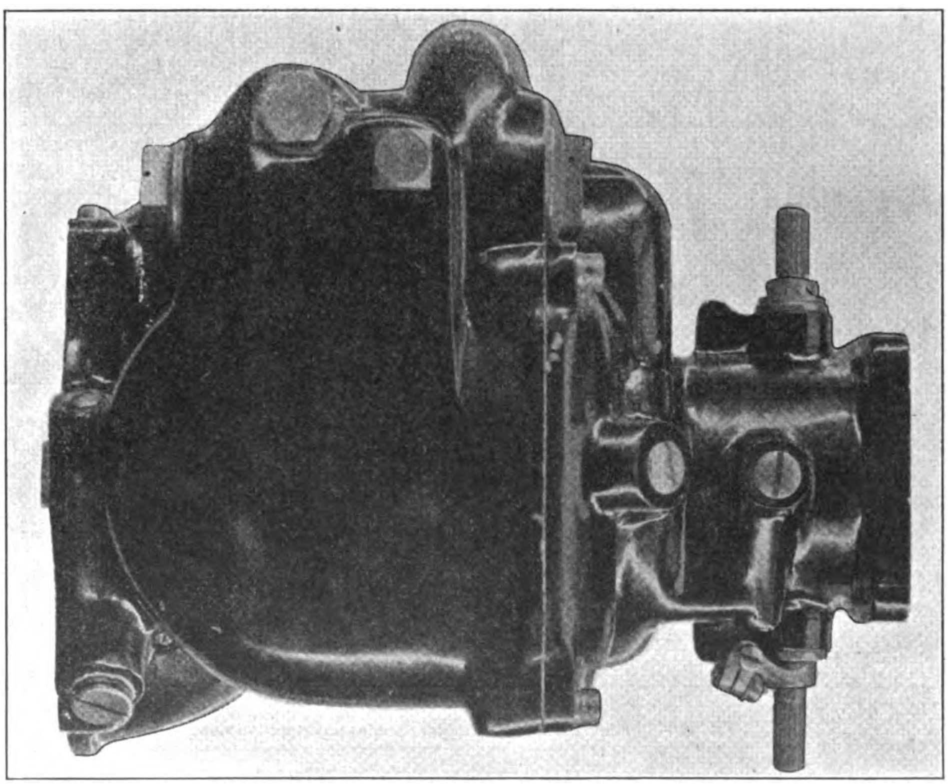


FIG. 10.—Stromberg NA-S6 carburetor. Side (floate hamber) view.

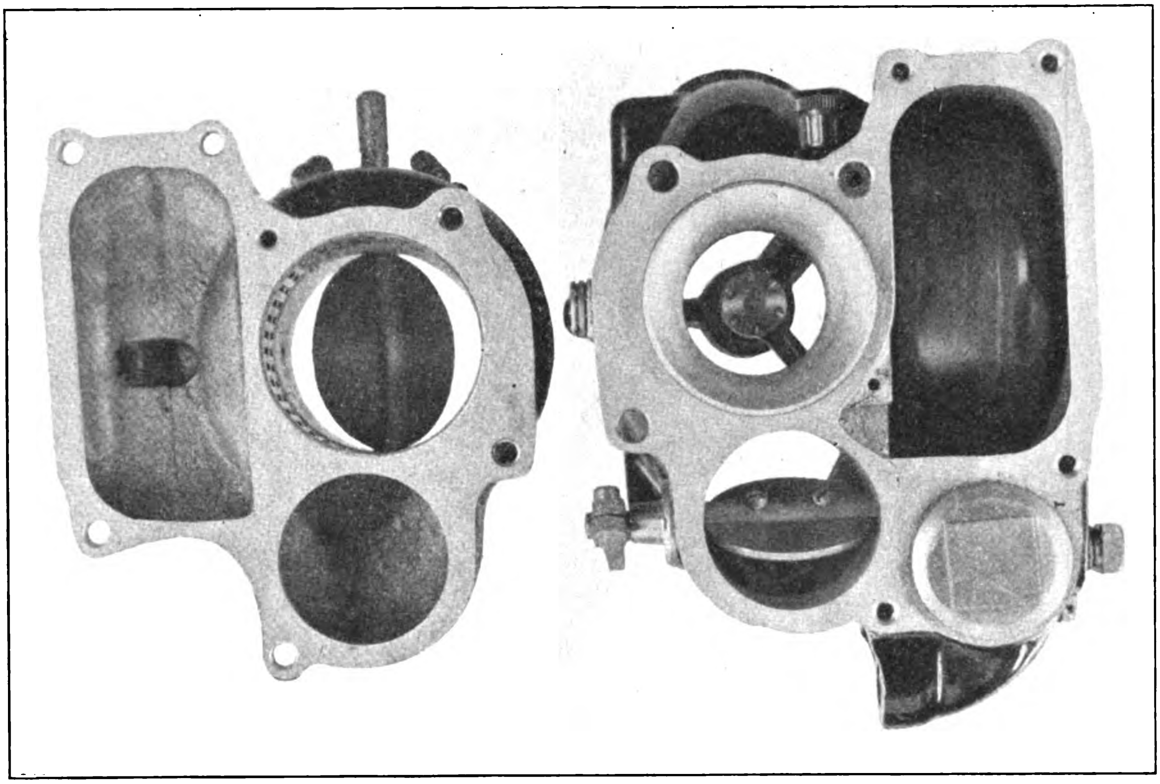


Fig. 11.—Stromberg NA-S6 carburetor. Sectional view.

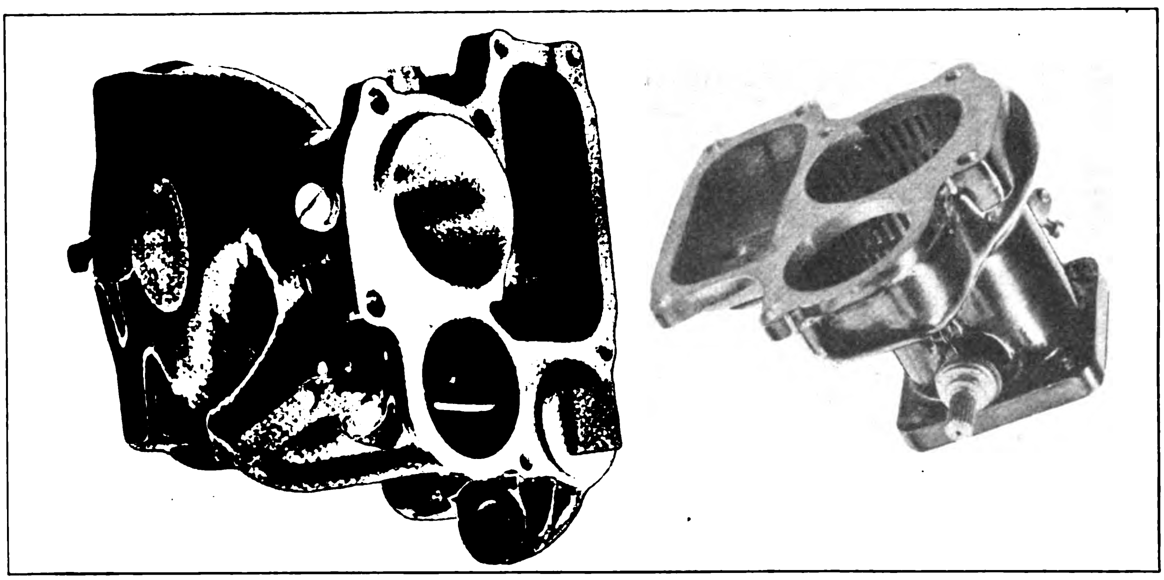


Fig. 12.—Stromberg NA-S6 carburetor. Sectional perspective view.

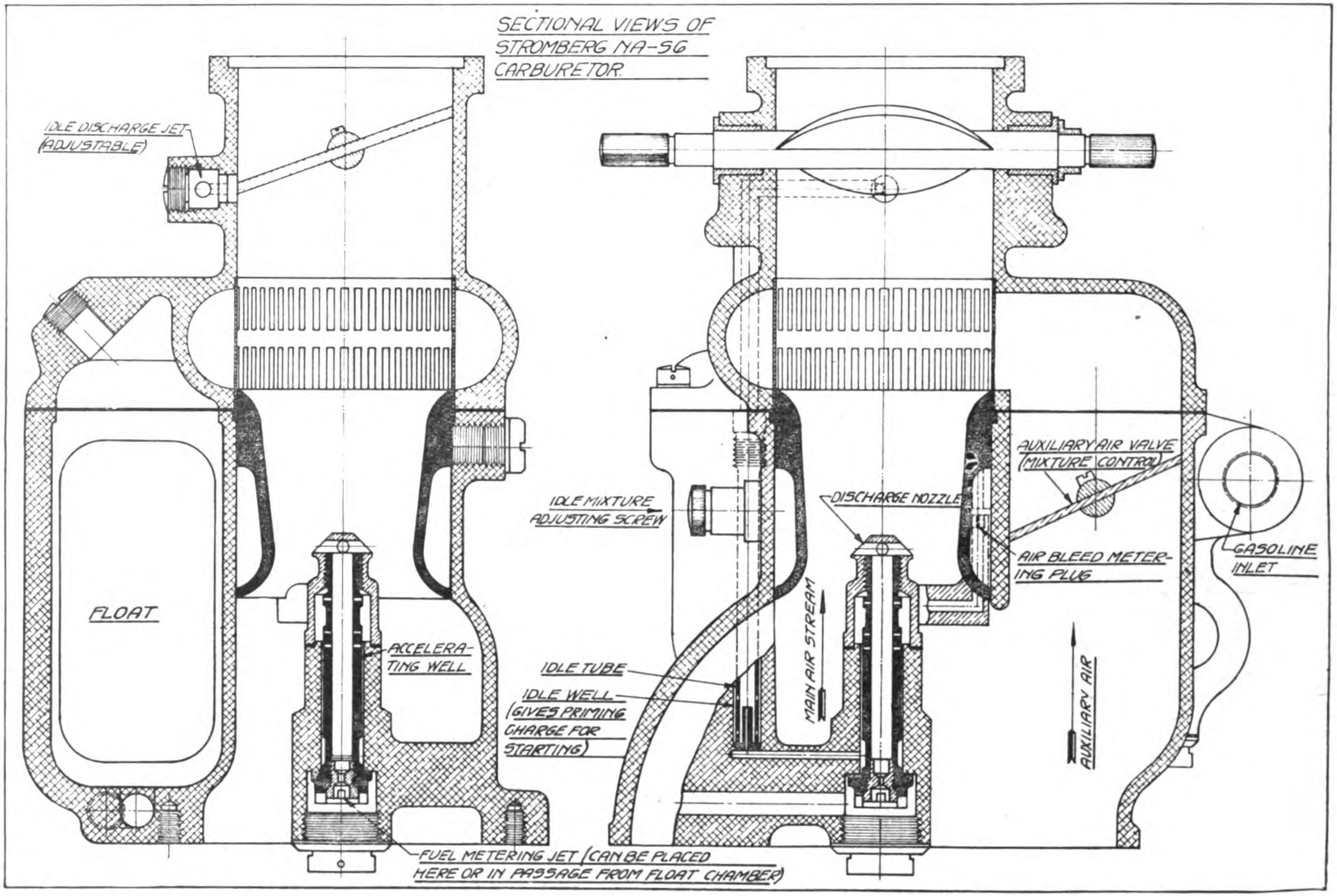


FIG. 13.—Stromberg NA-S6 carburetor. Sections through discharge nozzle.

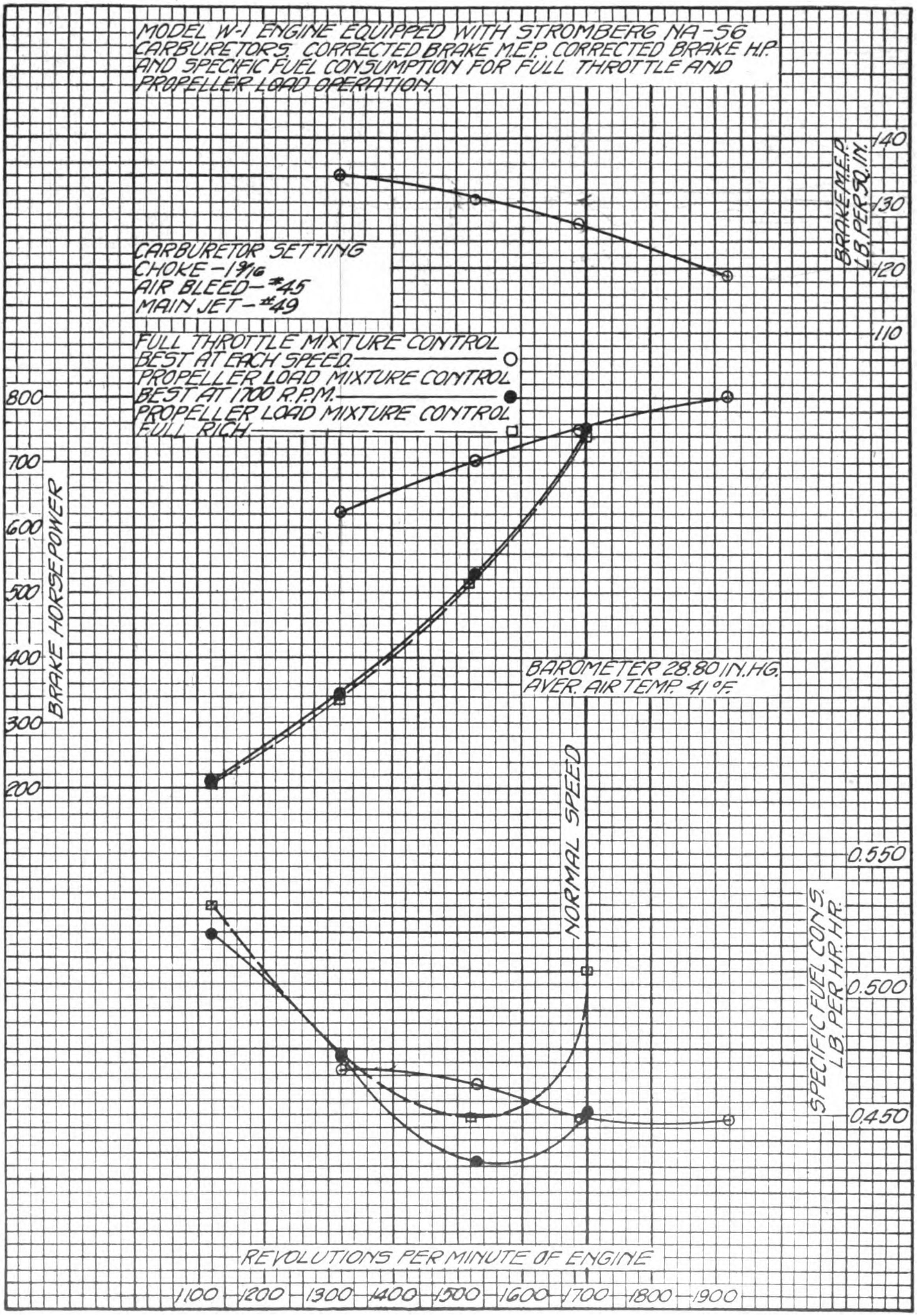

MODEL W-1 ENGINE EQUIPPED WITH STROMBERG NA-S6 CARBURETORS. CORRECTED BRAKE M.E.P. CORRECTED BRAKE H.P. AND SPECIFIC FUEL CONSUMPTION FOR FULL THROTTLE AND PROPELLER LOAD OPERATION.
CARBURETOR SETTING
CHOKE - 1 9/16
AIR BLEED - #45
MAIN JET - #49
FULL THROTTLE MIXTURE CONTROL BEST AT EACH SPEED
PROPELLER LOAD MIXTURE CONTROL BEST AT 1700 R.P.M.
PROPELLER LOAD MIXTURE CONTROL FULL RICH
BRAKE M.E.P. LB. PER SQ. IN.
140
130
120
110
800
700
600
500
400
300
200
BRAKE HORSEPOWER
BAROMETER 28.80 IN. HG.
AVER. AIR TEMP. 41 °F.
NORMAL SPEED
0.550
0.500
0.450
SPECIFIC FUEL CONS. LB. PER HP. HR.
REVOLUTIONS PER MINUTE OF ENGINE
1100
1200
1300
1400
1500
1600
1700
1800
1900

FIG. 14.

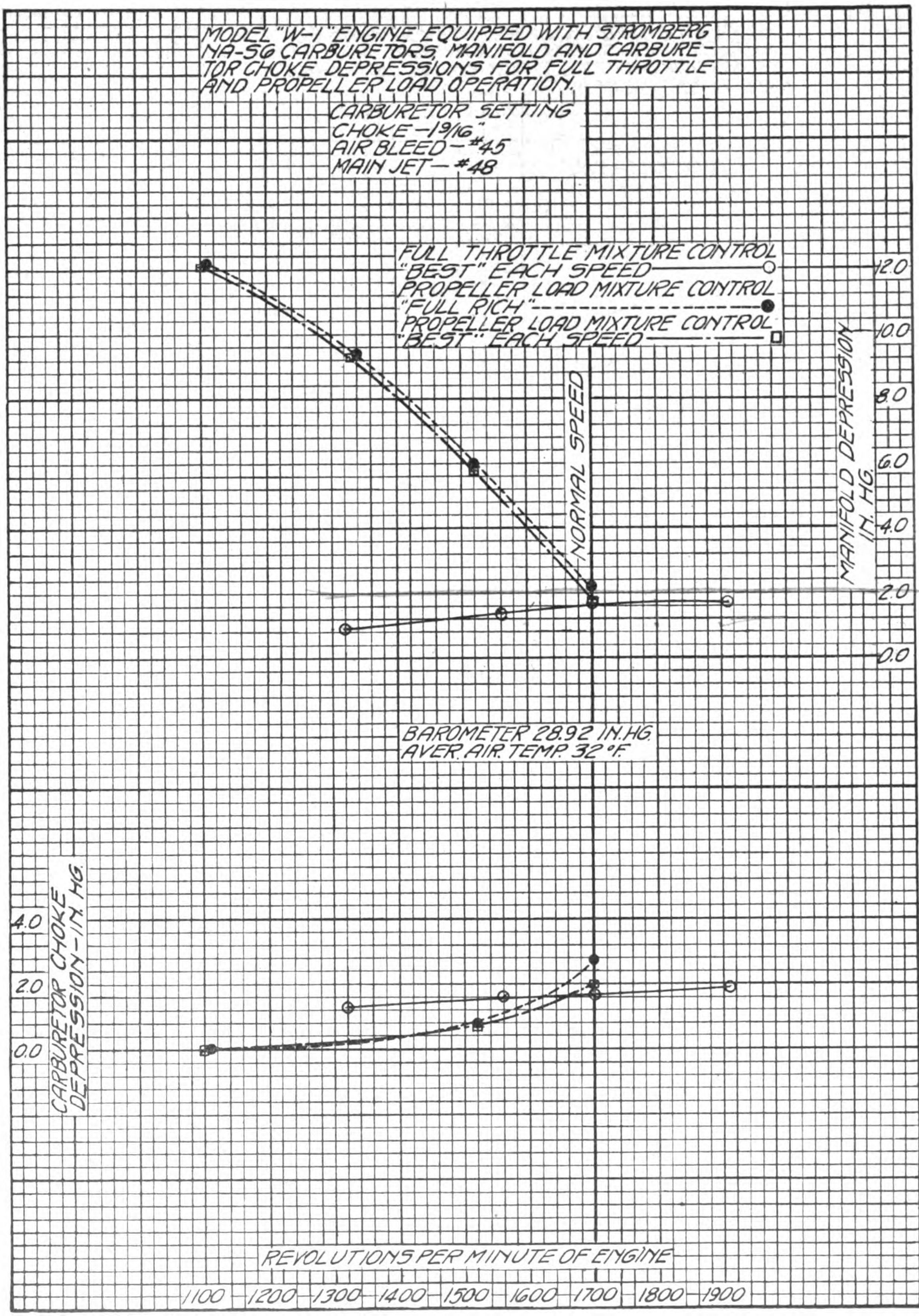

MODEL "W-1" ENGINE EQUIPPED WITH STROMBERG NA-S6 CARBURETORS, MANIFOLD AND CARBURETOR CHOKE DEPRESSIONS FOR FULL THROTTLE AND PROPELLER LOAD OPERATION.
CARBURETOR SETTING
CHOKE—19/16"
AIR BLEED—#45
MAIN JET—#48
FULL THROTTLE MIXTURE CONTROL "BEST" EACH SPEED
PROPELLER LOAD MIXTURE CONTROL "FULL RICH"
PROPELLER LOAD MIXTURE CONTROL "BEST" EACH SPEED
NORMAL SPEED
MANIFOLD DEPRESSION IN. HG.
12.0
10.0
8.0
6.0
4.0
2.0
0.0
BAROMETER 28.92 IN. HG.
AVER. AIR TEMP. 32 °F.
CARBURETOR CHOKE DEPRESSION—IN. HG.
4.0
2.0
0.0
REVOLUTIONS PER MINUTE OF ENGINE
1100
1200
1300
1400
1500
1600
1700
1800
1900

Fig. 15.

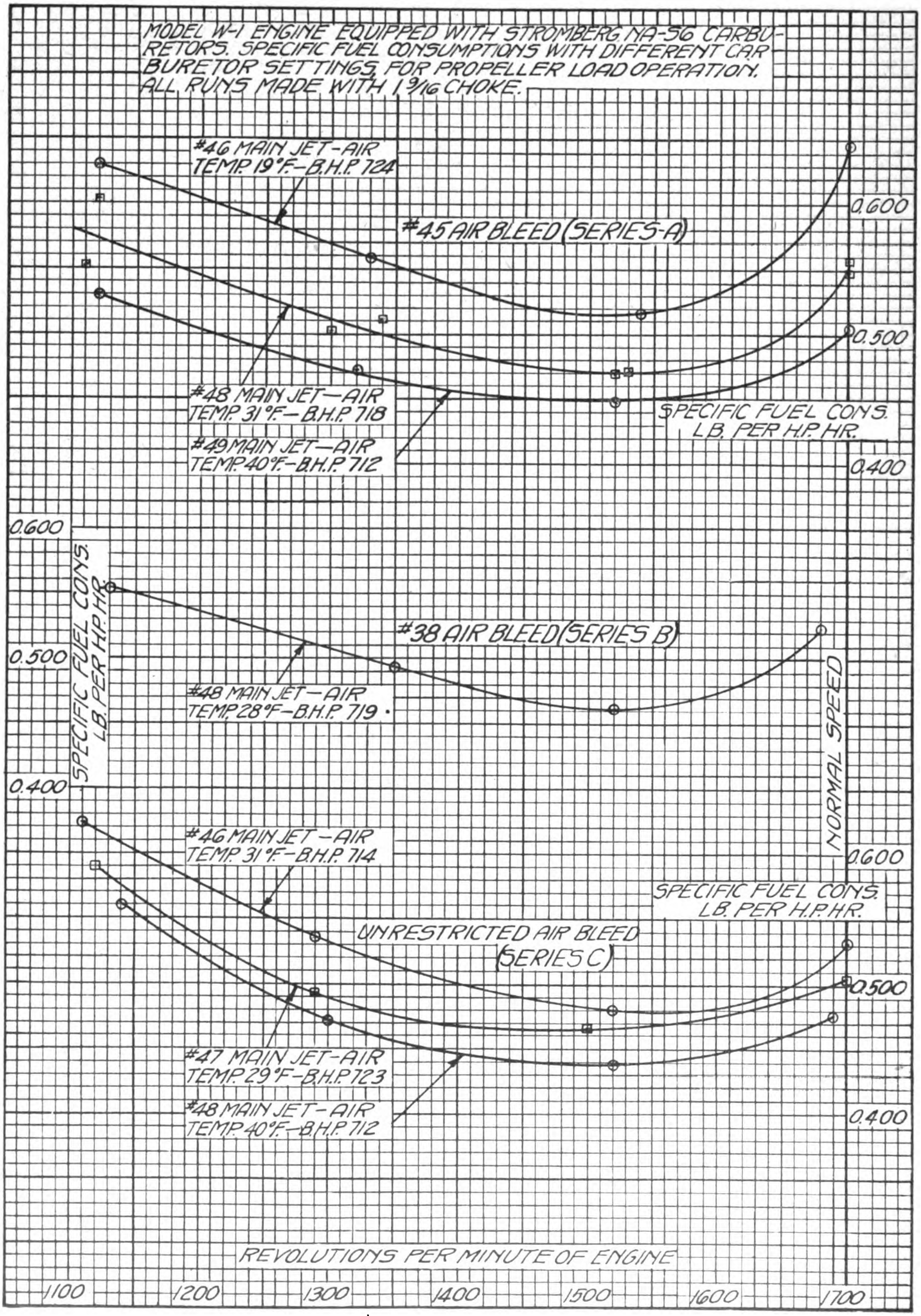

MODEL W-1 ENGINE EQUIPPED WITH STROMBERG NA-S6 CARBURETORS. SPECIFIC FUEL CONSUMPTIONS WITH DIFFERENT CARBURETOR SETTINGS FOR PROPELLER LOAD OPERATION. ALL RUNS MADE WITH 1 9/16 CHOKE.
#46 MAIN JET-AIR TEMP. 19°F.-B.H.P. 724
#45 AIR BLEED (SERIES-A)
#48 MAIN JET—AIR TEMP. 31°F.-B.H.P. 718
#49 MAIN JET—AIR TEMP. 40°F.-B.H.P. 712
SPECIFIC FUEL CONS. LB. PER H.P. HR.
0.600
0.500
0.400
#38 AIR BLEED (SERIES B)
#48 MAIN JET—AIR TEMP. 28°F-B.H.P. 719
SPECIFIC FUEL CONS. LB. PER H.P. HR.
NORMAL SPEED
#46 MAIN JET—AIR TEMP. 31°F.-B.H.P. 714
UNRESTRICTED AIR BLEED (SERIES C)
#47 MAIN JET-AIR TEMP. 29°F-B.H.P. 723
#48 MAIN JET-AIR TEMP. 40°F.-B.H.P. 712
REVOLUTIONS PER MINUTE OF ENGINE
1100
1200
1300
1400
1500
1600
1700

FIG. 16.

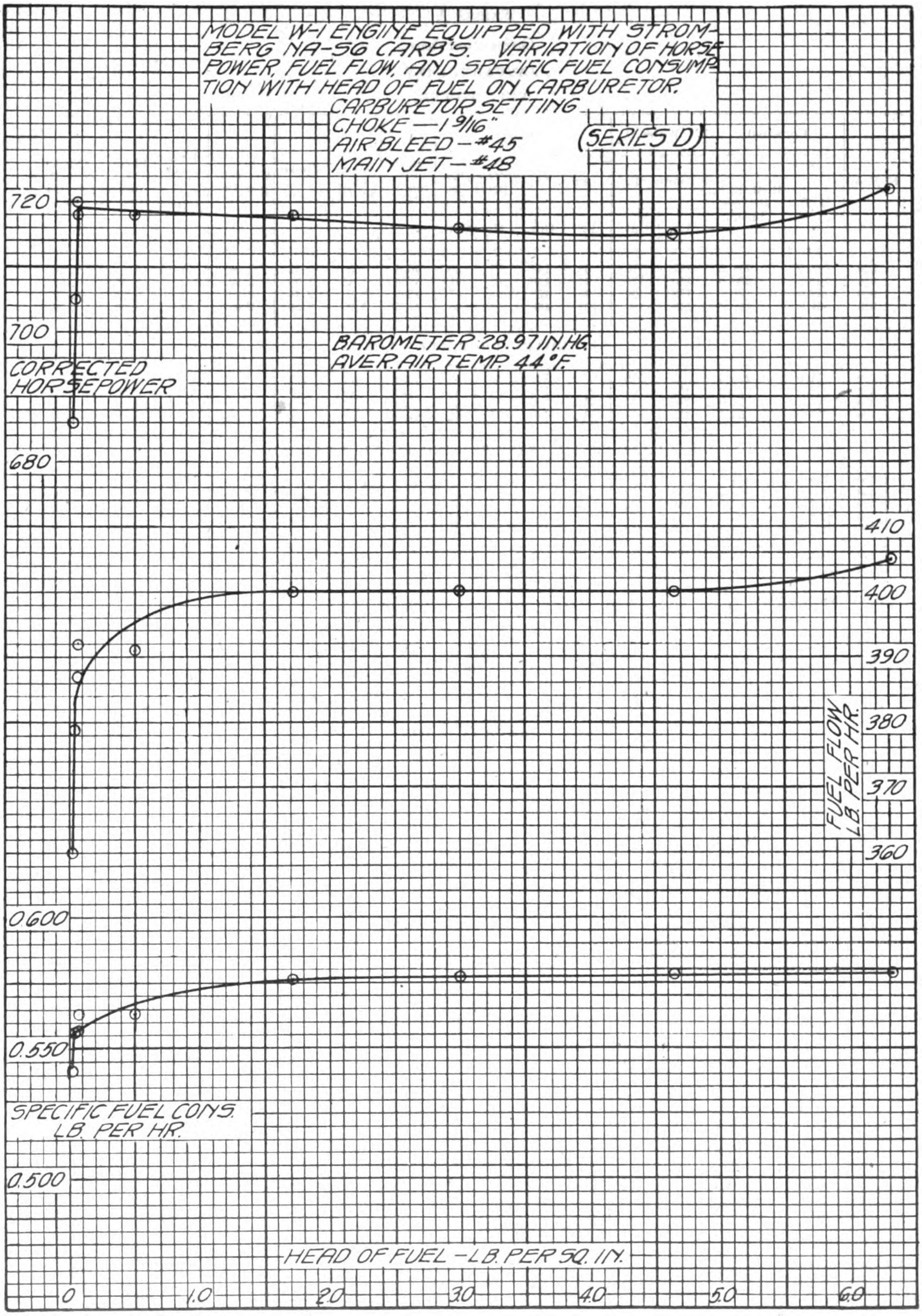

MODEL W-1 ENGINE EQUIPPED WITH STROMBERG NA-S6 CARB'S. VARIATION OF HORSEPOWER, FUEL FLOW, AND SPECIFIC FUEL CONSUMPTION WITH HEAD OF FUEL ON CARBURETOR.
CARBURETOR SETTING
CHOKE — 1 9/16"
AIR BLEED — #45
MAIN JET — #48
(SERIES D)
BAROMETER 28.97 IN. HG.
AVER. AIR TEMP. 44°F.
CORRECTED HORSEPOWER
720
700
680
FUEL FLOW LB. PER HR.
410
400
390
380
370
360
0.600
0.550
0.500
SPECIFIC FUEL CONS. LB. PER HR.
HEAD OF FUEL — LB. PER SQ. IN.
0
1.0
2.0
3.0
4.0
5.0
6.0

Fig. 17.

Series A.

Carburetion runs.

JANUARY 11, 1922.

FULL POWER.

R. P. M.	Corrected. H. P.	Corrected. B. M. E. P., lbs. per sq. in.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. In.	Oil. Temp., °F. Out.	Oil. Press., lbs. per sq. in. M.	Oil. Press., lbs. per sq. in. C. S.	Carb. air temp., °F.	Man. vac., in. hg.	Choke vac., in. hg.	Mix. cont. position.	Float chamber vac., in. H_2O.	Throttle position.	Fuel cons. lb. per H. P. hr.
1,320	623.0	134.5	147	170	94	144	55	50	40.0	1.0	1.55	3.00	0.0	8.25	0.467
1,530	702.0	130.6	150	170	94	150	55	47	41.0	1.45	1.90	3.00	0	8.25	.462
1,690	752.0	126.7	153	169	96	158	55	47	42.5	1.8	2.10	2.90	0	8.25	.448
1,920	801.0	118.7	148	169	102	166	54	45	41.5	1.9	2.50	2.65	0	8.25	.448

STANDARD PROPELLER LOAD.

R. P. M.	H. P.	B. M. E. P.	Water In.	Water Out.	Oil In.	Oil Out.	M.	C. S.	Carb. air temp.	Man. vac.	Choke vac.	Mix. cont.	Float chamber vac.	Throttle position.	Fuel cons.
1,700	754.0	126.3	151	170	96	146	56	50	40.0	1.7	2.1	2.95	0.0	8.25	0.451
1,530	528.0	98.3	152	167	96	156	54	45	41.0	3.7	.8	2.95	−.2	5.60	.432
1,320	343.0	74.0	156	169	96	150	55	52	41.0	6.4	.3	2.95	−.4	4.50	.472
1,120	209.0	53.1	155	170	96	140	55	55	41.0	9.7	.1	2.95	−.5	3.70	.519

FULL RICH AND BEST SETTING PROPELLER LOAD.

R. P. M.	H. P.	B. M. E. P.	Water In.	Water Out.	Oil In.	Oil Out.	M.	C. S.	Carb. air temp.	Man. vac.	Choke vac.	Mix. cont.	Float chamber vac.	Throttle position.	Fuel cons.
1,700	740.0	124.0	151	168	94	146	55	48	42.0	2.1	2.8	F. R.	0.5	8.25	0.505
1,690	749.0	126.2	151	172	94	158	54	46	40.0	1.8	2.1	2.85	0	8.25	.449
1,520	517.5	97.0	150	173	96	158	54	43	40.0	5.2	.9	F. R.	−.2	5.00	.449
1,490	503.0	96.2	154	174	96	156	54	47	40.0	5.5	1.15	2.20	−.2	5.00	.444
1,320	336.5	72.6	153	170	96	150	54	50	40.0	9.9	.2	F. R.	−.2	4.25	.473
....	....	....	....	....	....	....	....	....	....	....	....	F. R.	....	....	....
1,120	204.0	51.8	154	168	96	142	55	51	41.0	13.1	.1	F. R.	−.7	3.60	.530
....	....	....	....	....	....	....	....	....	....	....	....	F. R.	....	....	....

Carburetor settings:
- Carburetor used, Stromberg NA-S6.
- Chokes, 1$\frac{9}{16}$ inches.
- Main jets, No. 49.
- Air bleed, No. 45.
- Barometer, 28.80 in. hg.

Remarks:
- Mixture control has 10 divisions.
  - F. R.=full rich=2.00.
  - F. L.=full lean=6.00.
- Throttle has 10 divisions.
  - Closed=0.4.
  - Open=8.25.
- Oil pressure—
  - M=main at pump.
  - C. S.=in cam-shaft housing.

JANUARY 12, 1922.

FULL POWER.

R. P. M.	Corrected. H. P.	Corrected. B. M. E. P., lbs. per sq. in.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. In.	Oil. Temp., °F. Out.	Oil. Press., lbs. per sq. in.	Carb. air temp., °F.	Man. vac., in hg.	Choke vac., in hg.	Mix. cont. position.	Float chamber vac., in H_2O.	Throttle position.	Fuel cons. lb. per H. P. hr.
1,320	628.0	135.4	140	170	108	142	54	34	0.9	1.3	3.55	0.1	8.25	0.478
1,560	726.0	132.5	150	170	108	150	54	30	1.4	1.6	3.60	.2	8.25	.450
1,700	752.0	127.8	150	172	110	158	54	36	1.65	1.7	3.50	.3	8.25	.447
1,910	804.0	120.0	....	....	....	....	55	34	1.70	1.9	3.40	.3	8.25	.450

STANDARD PROPELLER LOAD.

R. P. M.	H. P.	B. M. E. P.	Water In.	Water Out.	Oil In.	Oil Out.	Oil Press.	Carb. air temp.	Man. vac.	Choke vac.	Mix. cont.	Float chamber vac.	Throttle position.	Fuel cons.
1,720	772.0	127.8	150	170	101	146	54	31	1.8	2.2	2.70	1.0	8.25	0.491
1,530	528.0	98.3	152	170	104	150	54	34	5.0	.6	2.70	.0	5.25	.440
1,320	340.0	73.3	153	170	104	146	53	30	8.7	.3	2.70	−.5	4.25	.482
1,100	198.5	51.4	156	170	104	138	52	30	11.8	[1] 1.3	2.70	−.2	3.20	.534

FULL-RICH AND BEST-SETTING PROPELLER LOAD.

R. P. M.	H. P.	B. M. E. P.	Water In.	Water Out.	Oil In.	Oil Out.	Oil Press.	Carb. air temp.	Man. vac.	Choke vac.	Mix. cont.	Float chamber vac.	Throttle position.	Fuel cons.
1,700	742.0	124.2	154	168	102	142	53	31	2.2	2.75	F. R.	0.9	8.25	0.557
1,700	767.0	128.5	152	170	104	152	55	35	1.75	2.0	3.00	−.2	8.25	.465
1,520	522.0	97.8	153	170	108	154	54	30	6.0	.8	F. R.	−.5	5.00	.470
1,520	515.0	96.5	152	170	109	152	53	31	5.8	.7	2.40	−.3	5.00	.460
1,340	343.0	73.0	154	170	110	148	53	31	9.4	.25	F. R.	−1.0	4.15	.511
1,330	339.0	72.6	154	170	108	142	52	32	9.3	[1] 3.2	2.35	−.5	4.15	.476
1,110	206.0	52.8	156	170	106	138	52	31	12.2	0.0	F. R.	−1.6	3.65	.552
1,100	203.0	52.5	158	168	104	132	52	30	12.1	[1] .8	2.40	−.7	3.65	.532

[1] In. H_2O.

Carburetor settings:
- Carburetor used, NA-S6.
- Chokes, 1$\frac{9}{16}$ inches.
- Main jets, No. 48.
- Air bleed, No. 45.
- Barometer, 28.92 in. hg.

Remarks:
- Mixture control has 10 divisions.
  - F. R.=full rich=2.00.
  - F. L.=full lean=6.00.
- Throttle has 10 divisions.
  - Closed=0.4.
  - Open=8.25.

Series A—Continued.

Propeller-load runs.

JANUARY 12, 1922.

R. P. M.	Corrected.		Water.		Oil.				Carb. air temp. °F.	Man. vac., in. hg.	Choke vac., in. hg.	Mixture control position.	Fuel cons., lb. per. H. P. hr.
	H. P.	B. M. E. P., lbs. per sq. in.	Temp., °F.		Temp., °F.		Press., lbs. per sq. in.						
			In.	Out.	In.	Out.	M.	C. S.					
1,700..	746	125.0	154	173	92	130	55	38	34	2.2	2.8	F. R....	0.548
1,530..	522	97.2	151	167	98	140	54	40	30	6.0	.85	F. R....	.471
1,300..	330	72.3	160	170	100	140	53	43	29	9.5	.25	F. R....	.502
1,120..	206	52.4	158	168	100	136	....	....	30	12.2	.10	F. R....	.603

Carburetor settings:
- Carburetor used, Stromberg NA-S6.
- Chokes, 1$\frac{3}{16}$ inches.
- Main jets, No. 48.
- Air bleed, No. 45.

Barometer, 28.95 in. hg.

Remarks:
- Mixture control has 10 divisions.
  - F. R.=full rich=2.00.
  - F. L.=full lean=6.00.
- Oil pressure—
  - M.=main at pump.
  - C. S.=in cam-shaft housing.

JANUARY 23, 1922.

R. P. M.	Corrected.		Water.		Oil.			Carb. air temp. °F.	Man. vac., in. hg.	Choke vac., in. hg.	Mixture control position.	Fuel cons., lb. per H. P. hr.
	H. P.	B. M. E. P., lbs. per sq. in.	Temp., °F.		Temp., °F.		Press., lbs. per sq. in.					
			In.	Out.	In.	Out.						
1,700	730	122.2	154	170	106	134	52	20	2.2	2.8	F. R.	0.646
1,540	520	96.2	152	172	108	136	51	18	5.9	.9	F. R.	.516
1,330	333	71.3	150	170	110	136	50	18	9.0	.35	F. R.	.559
1,120	201	51.1	150	168	108	134	49	18	11.7	.20	F. R.	.630

Carburetor settings:
- Carburetor used, Stromberg NA-S6.
- Chokes, 1$\frac{3}{16}$ inches.
- Main jets, No. 46.
- Air bleed, No. 45.

Barometer, 29.60 in. hg.

Remarks:
- Mixture control has 10 divisions.
  - F. R.=full rich=2.00.
  - F. L.=full lean=6.00.

Series B.—*Propeller-load run.*

R. P. M.	Corrected.		Water.		Oil.			Carb. air temp. °F.	Man. vac., in. hg.	Choke vac., in. hg.	Mixture control position.	Fuel cons., lb. per H. P. hr.
	H. P.	B. M. E. P., lbs. per sq. in.	Temp., °F.		Temp., °F.		Press., lbs. per sq. in.					
			In.	Out.	In.	Out.						
1,680	735.0	124.5	147	166	116	136	52	29	2.05	2.7	F. R.	0.524
1,520	522.0	97.8	146	166	120	146	50	27	5.1	.95	F. R.	.461
1,350	346.0	73.0	151	170	120	144	50	28	8.5	.35	F. R.	.493
1,130	205.5	51.8	150	167	120	140	50	27	11.7	.15	F. R.	.554

Carburetor settings:
- Carburetor used, Stromberg NA-S6.
- Chokes, 1$\frac{3}{16}$ inches.
- Main jets, No. 48.
- Air bleed, No. 38.

Barometer, 29.27 in. hg.

Remarks:
- Mixture control has 10 divisions.
  - F. R.=full rich=2.00.
  - F. L.=full lean=6.00.

Date, Jan. 19, 1922.

SERIES C.—*Propeller-load runs.*

WITH No. 48 MAIN JETS.

R. P. M.	Corrected. H. P.	Corrected. B. M. E. P., lbs. per sq. in.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. In.	Oil. Temp., °F. Out.	Oil. Press., lbs. per sq. in.	Carb. air temp., °F.	Man. vac., in. hg.	Choke vac., in. hg.	Mixture control position.	Fuel cons., lbs. per H. P. hr.
1,670	701	119.5	153	174	106	156	52	52	2.1	2.85	F. R.	0.487
1,520	518	97.1	152	171	102	158	52	50	4.7	1.1	F. R.	.439
1,300	329	72.1	152	171	96	152	52	40	8.4	.25	F. R.	.471
1,140	206	51.4	150	168	96	144	52	39	11.6	.2	F. R.	.560
Check. 1,690	728	122.6	149	160	90	144	52	39	2.1	2.8	F. R.	.477

WITH No. 47 MAIN JETS.

R. P. M.	Corrected. H. P.	Corrected. B. M. E. P., lbs. per sq. in.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. In.	Oil. Temp., °F. Out.	Oil. Press., lbs. per sq. in.	Carb. air temp., °F.	Man. vac., in. hg.	Choke vac., in. hg.	Mixture control position.	Fuel cons., lbs. per H. P. hr.
1,700	740.0	124.0	152	170	104	134	53	30	2.2	2.7	F. R.	0.505
1,500	508.0	96.6	151	170	106	138	53	29	6.0	.65	F. R.	.467
1,290	322.0	71.1	152	172	108	136	52	29	11.6	.25	F. R.	.493
1,120	202.5	51.5	146	164	108	136	51	29	16.4	....	F. R.	.590

WITH No. 46 MAIN JETS.

R. P. M.	Corrected. H. P.	Corrected. B. M. E. P., lbs. per sq. in.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. In.	Oil. Temp., °F. Out.	Oil. Press., lbs. per sq. in.	Carb. air temp., °F.	Man. vac., in. hg.	Choke vac., in. hg.	Mixture control position.	Fuel cons., lbs. per H. P. hr.
1,700	730.0	122.4	150	170	96	130	51	32	2.1	2.6	F. R.	0.531
1,520	518.0	97.1	152	172	100	140	51	31	5.5	.8	F. R.	.480
1,290	325.0	71.7	152	172	106	140	51	30	9.8	.45	F. R.	.535
1,110	202.5	52.0	150	169	106	138	51	31	13.5	....	F. R.	.624

Carburetor settings:
Carburetor used, Stromberg NA-S6.
Chokes, $1\frac{3}{16}$ inches.
Air bleed, unrestricted.
Barometer, 29.25 in. hg.

Remarks:
Mixture control has 10 divisions.
F. R.=full rich=2.00.
F. L.=full lean=6.00.
Date, Jan. 20 and 21, 1922.

SERIES D.—*Carburetor-head test.*

R. P. M.	Corrected. H. P.	Corrected. B. M. E. P., lbs. per sq. in.	Water. Temp., °F. In.	Water. Temp., °F. Out.	Oil. Temp., °F. In.	Oil. Temp., °F. Out.	Oil. Press., lbs. per sq. in.	Carb. air temp., °F.	Man. vac., in. hg.	Choke vac., in. hg.	Mixture control position.	Fuel head on carb., in. gas.	Float chamber vac., in. H_2O.	Fuel cons., lb. per H. P. hr.
1,680	718	121.7	148	169	114	154	53	....	2.1	2.8	F. R.	2.8	1.1	0.557
1,670	705	120.2	154	176	104	142	52	44	2.1	2.8	F. R.	2.0	.3	.556
1,640	686	119.2	150	172	112	154	52	45	2.0	2.8	F. R.	1.2	4.4	.542
1,690	720	121.3	152	172	112	150	53	....	2.1	2.8	F. R.	3.0	1.1	.563
1,680	718	121.7	139	160	114	154	52	42	2.0	2.8	F. R.	19.8	.4	.563
1,680	718	121.7	142	162	114	146	54	....	2.1	2.65	F. R.	[1] 3.5	.5	.576
1,680	716	121.4	146	166	118	156	52	44	2.1	2.7	F. R.	[1] 6.2	.6	.577
1,670	715	121.8	146	168	118	158	52	43	2.05	2.7	F. R.	[1] 9.5	.4	.578
1,690	722	121.6	148	169	120	160	53	43	2.1	2.7	F. R.	[1] 12.9	.3	.579

[1] Inches of hg.

Carburetor settings:
Carburetor used, NA-S6 Stromberg.
Chokes, $1\frac{3}{16}$ inches.
Main jets, No. 48.

Carburetor settings (continued):
Air bleed, No. 45.
Barometer, 28.97 in. hg.
Date, Jan., 18, 1922.

SERIES D.—*Data of flooding test of 5 NA-S6 Carburetors.*

Carburetor No.	Flooding pressure. In. hg.	Flooding pressure. Lbs. per sq. in.	Remarks.
1	6.8	3.33	After commencement of flooding runs a continuous stream.[1]
2	12.6	6.18	After commencement of flooding drips only a small amount.
3	12.6	6.18	Do.
4	13.5	6.62	Do.
5	19.3	9.46	Do.

[1] The float of No. 1 curburetor was found to be in a collapsed condition and after repair the carburetor would stand a pressure of over 6 pounds per square inch before flooding commenced.

Date, Jan. 18, 1922.

SERIES E.—*Flooding test of carburetors at torque stand. Engine A. S. No. 94626. Carburetors NA-S6B.*

FLOODING PRESSURE.

Carburetor No.	Engine idling 375-500 R. P. M. Ins. hg.	Engine idling 375-500 R. P. M. Lbs. per sq. in.	Engine not running. Ins. hg.	Engine not running. Lbs. per sq. in.	Engine idling 400-450 R. P. M. Ins. hg.	Engine idling 400-450 R. P. M. Lbs. per sq. in.
1L	32.5	15.9	18.2	8.9	....	....
1R	....	....	14.8	7.3	....	....
2L	....	....	12.8	6.3	....	....
2R	17.8	8.7	16.8	8.2	....	....
3L	....	....	16.3	8.0	....	....
3R	....	....	17.8	8.7	30.8	15.1

NOTE.—The apparatus limited the pressure obtainable to 33.5 in. hg. (16.3 lbs. per sq. in.), and where there are no figures in the above table it indicates that the carburetors had not flooded when this limit was reached.

Date, Mar. 7, 1922.

SERIES F.

Full-power heat rejection.

FIRST RUN.

R. P. M.	Corrected.		Water.				Oil.			Carb. air temp., °F.	Man. vac., in. hg.	Choke vac., in. hg.	Mixture control position.	Fuel cons., lbs. per H. P. hr.
	H. P.	B. M. E. P. lbs. per sq. in.	Temp., °F. Before. In.	Temp., °F. Before. Out.	Temp., °F. After. In.	Temp., °F. After. Out.	Temp., °F. In.	Temp., °F. Out.	Press., lbs. per sq. in.					
1,640	728	126.5	147	168	144.5	165.5	106	156	55	48	1.9	1.9	3.00	0.490
1,680	739	125.4	145	167	148.5	170.0	110	164	54	49	1.9	1.8	3.00	.480
1,830	766	119.2	149.5	171	150	171.5	112	170	55	49	1.95	1.9	3.00	.466

SECOND RUN.

1,630	720	125.7	146	168.5	152	175.0	96	156	54	49	1.8	1.85	3.00	0.484
1,680	736	124.7	154	176.5	152	174.0	96	160	55	51	1.85	1.9	3.00	.485
1,810	742	116.7	151.5	173.0	151	172.5	96	168	53	51	1.9	2.2	2.75	.496

Carburetor settings:
- Carburetor used, NA-86.
- Chokes, $1\frac{9}{16}$ inches.
- Main jets, No. 48.
- Air bleed, No. 45.

Barometer, 28.91 in. hg.

Remarks:
- Mixture control—
  - F. L.=full lean=6.00.
  - F. R=full rich=2.00.

Date, Jan. 18, 1922.

Data for all runs in this report:
- Dynamometer, No. 3.
- Length of brake arm, 21 in.
- Kind of oil used—Spec. 2-23 (grade 3).
  Viscosity 115°-125° S. at 210° F.
- Fuel used, spec. gravity .705 at 60° F.

Summary of model W-1 heat-rejection data (corrected).

RUN NO. 1.

R. P. M.	Engine actual B. H. P.	Air temp., °F.	Cooling water.					Corr. water temp., °F.			B. T. U. per min. rejected to water.	
			Venturi No. 1. Corr. head, in. hg.	Venturi No. 1. Flow, lbs. per hr.	Venturi No. 2. Corr. head, in. hg.	Venturi No. 2. Flow, lbs. per hr.	Total. Flow, lbs. per hr.	In.	Out.	Diff.	Total.	Per actual B. H. P.
1,640	703	48	10.9	32,400	4.4	21,100	53,500	143.9	164.3	20.4	18,200	25.9
1,680	714	49	11.25	33,000	3.55	19,000	52,000	144.9	166.0	21.1	18,290	26.0
1,830	740	49	11.85	33,850	3.65	19,250	53,100	147.8	168.7	20.9	18,500	25.0

RUN NO. 2.

1,630	695	49	27.7	51,850	....	....	51,850	147.0	169.2	22.2	19,180	27.6
1,680	711	51	29.05	53,150	....	....	53,150	150.9	172.7	21.8	19,310	27.15
1,810	716	51	32.10	56,000	....	....	56,000	149.2	170.2	21.0	19,600	27.35

Barometer, 28.91 in. hg.

McCOOK FIELD REPORT, SERIAL No. 1920

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | August 15, 1922 | No. 362

STATIC TEST OF THOMAS-MORSE MB-6 AIRPLANE

(AIRPLANE SECTION, S. & A. BRANCH)

Prepared by E. R. Weaver
Engineering Division, Air Service
McCook Field, Dayton, Ohio
May 2, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.

By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

STATIC TEST OF THOMAS-MORSE MB-6 AIRPLAN

SUMMARY OF RESULTS.

Airplane: Thomas-Morse MB-6.
Type: Biplane.
Total weight: 2,023 pounds.
Wing cellule, weight: 216 pounds.
Wing area: 150.34 square feet.

Engine: 400 horsepower, Wright.
Description: This airplane is a single seater racer, mounting a 400 horsepower high compression 8-cylinder Wright engine. The wings and fuselage are of wood construction and covered with fabric.

Results of tests.

Date.	Part tested.	Load required.	Pounds per square foot of factor supported.	Failed at—	Weight.	Failure.
1921. Oct. 14	Horizontal stabilizer.	35 pounds per square foot.	35 pounds per square foot.		1.52 pounds per square foot.	Structurally satisfactory.
14	Elevator	do	do		1.12 pounds per square foot.	Do.
14	Elevator control	7	7			Cross member supporting the control stick showed a torsional deflection of one-half inch.
Oct. 15	Vertical fin	30 pounds per square foot.	40 pounds per square foot.		0.93 pound per square foot.	Structurally satisfactory.
15	Rudder	do	do		1.21 pounds per square foot.	Do.
15	Rudder control	6	8			Do.
Oct. 25	Ailerons	35 pounds per square foot.	37.5 pounds square foot.		1.28 pounds per square foot.	Do.
25	Aileron control	7	7.5			Do.
	Wing cellule:					
Oct. 20	High incidence	8.5	8.5	9	1.43 pounds per square foot.	Do.
Oct. 18	Low incidence	5.5	5.5		do	Do.
Oct. 24	Six foot length of leading edge.	14	20	20.8		Do.
Oct. 27	Fuselage	7	10.5	11	140.5 pounds	Do.
Oct. 29	Tail skid	36-inch drop		12-inch drop		Structurally unsatisfactory.
	Chassis:					
Nov. 1	Struts	6	7	8		
	Axle	5.5	7			
	Shock absorber.	5	7			Structurally satisfactory.

DISCUSSION.

To the wing area should be added the area of the landing chassis aerofoil which is 5.11 square feet; this makes the total effective aerofoil 155.45 square feet. From the total area of the upper wing the area of the two built-in radiators (4.31 square feet) has been deducted. The cross member supporting the control stick is the only part of the control system that showed any weakness, this member should be heavier. The tail skid is weak and the tail skid shock absorber should be redesigned.

OBJECT.

This static test was conducted for the purpose of determining the structural strength of the Thomas-Morse MB-6 airplane submitted in accordance with Contract No. 370. This airplane bore the A. S. No. 68538.

DATE AND PLACE.

The following tests were performed at McCook Field, Dayton, Ohio, on dates as follows:

1. Oct. 14, 1921.......... Elevator and stabilizer.
2. Oct. 15, 1921.......... Rudder and fin.
3. Oct. 25, 1921.......... Ailerons.
4. Oct. 18, 1921.......... Wing cellule (low incidence).
5. Oct. 20, 1921.......... Wing cellule (high incidence).
6. Oct. 27, 1921.......... Fuselage.
7. Oct. 29, 1921.......... Tail skid.
8. Nov. 1, 1921.......... Landing chassis.
9. Oct. 24, 1921.......... Leading edge.

WITNESSES.

Lieut. C. N. Monteith... Tests Nos. 1, 2, 4, 5, 7.
Lieut. E. W. Dichman... Tests Nos. 1, 2, 3, 4, 5, 6, 8.
Lieut. J. A. Macready.... Tests Nos. 4, 5, 6.
Lieut. S. P. Mills....... Tests Nos. 4, 5, 6.
B. C. Boulton........... Test No. 7.
W. E. Savage........... Tests No. 1, 2, 3, 4, 5, 6, 7, 8, 9.
D. B. Weaver............ Tests No. 1, 2, 3, 4, 5, 6, 7, 8, 9.

GENERAL DESCRIPTION.

The Thomas-Morse MB-6 airplane is a single-seater, racing-type biplane of wood construction. The airplane mounts a high-compression 8-cylinder Wright 400-horsepower engine.

The desired performance is as follows:

(*a*) High speed, 175 miles per hour.
(*b*) Climb, not important.
(*c*) Ceiling, not important.
(*d*) Landing speed, not in excess of 75 miles per hour.

Total weight, 2,023 pounds.

Wing area, 155.45 sq. feet including area of landing chassis airfoil.

Weight per square foot, 13.01 pounds.

Weight per horsepower, 5.057 pounds.

Airfoil, R. A. F.-15.

The list of equipment may be found in Section IV of contract No. 370.

Figure 1 is a plan view of the MB-6 airplane.

Figure 2 is a front and side view of the MB-6 airplane.

WING CELLULE.

DESCRIPTION.

The wing construction is entirely of wood. The spars are laminated spruce built up of plies one-eighth inch in thickness. The ribs are plywood with spruce cap strips. The upper wing panel has spars that extend the length of the wing, while the spars of the lower panels are short, being joined by fittings to the lower longerons. The leading edge strip is spruce and the trailing edge is made by connecting the ribs with a wire.

Figure 3 is a drawing of the upper wing structure.

Figure 4 is a drawing of the lower wing structure.

Figure 5 shows typical spar sections.

PROCEDURE FOR TEST (LOW INCIDENCE).

The wings were assembled on the airplane as for flight and the airplane inverted and loaded in accordance with the loading schedule in Figure 6.

The angle of inclination of the wing chord to the horizontal (angle γ) was 5° 52′ trailing edge down. This was determined from the high-speed angle of incidence α and the angle β between the lift and the resultant air force.

$$\alpha=0° \ 48'$$
$$\beta=\cot^{-1} 8.55=6° \ 40'$$
$$\gamma=\alpha-\beta=6° \ 40'-(48')=5° \ 52'$$

The center of gravity of the load was located at 40 per cent of the wing chord from the leading edge.

The wings were required to support a load factor of 5.5.

RESULTS.

The wings supported a load factor of 5.5 without signs of failure.

The deflections are tabulated in Figure 7.

Figure 8 shows the spar deflection curves.

CONCLUSION.

The wings supported the required load in a satisfactory manner.

PROCEDURE FOR TEST (HIGH INCIDENCE).

The airplane was reset for the high incidence test, with the wing chord at an angle of −5° 39′ to the horizontal with leading edge down. The wings were loaded in accordance with the loading schedule in Figure 9. The angle of inclination (γ) was determined from the angle of maximum lift α and β, the angle between the lift and the resultant air force.

$$\alpha=14° \ 48'$$
$$\beta=\cot^{-1} 6.2=9° \ 9'$$
$$\gamma=\beta-\alpha=9° \ 9'-(14° \ 48')= -5° \ 39'$$

RESULTS.

The required load factor for the high-incidence test was 8.5. The wings supported this load satisfactorily. At a load factor of 9 the left rear strut failed in compression when the strut fitting bolt sheared.

Figure 10 gives the spar deflections in inches.

Figure 11 shows the spar deflection curves.

Figure 25 is a photograph of the strut failure.

Figure 26 is a photograph of the strut fitting.

TABLE I.—*Strength properties of laminated spruce wing beams from the Thomas-Morse MB-6 airplane.*

Airplane member.	Moisture content (per cent).	Specific gravity.	Modulus. Rupture (pounds per square inch).	Modulus. Elasticity (1,000 pounds per square inch).	Fiber stress at elastic limit (pounds per square inch).	Compression parallel to grain (pounds per square inch).	Loading and span.
Lower left:							
Rear	8.85	0.501	9,370	2,120	6,290	8,460	Third point, 60 in.
Front	9.24	.515	9,890	2,010	6,180	7,520	Do.
Upper:							
Rear	8.52	.454	8,500	1,802	5,810	7,500	Do.
Front	8.57	.457	8,560	1,892	5,560	7,260	Do.

DISCUSSION.

Examination of the strut failure revealed diagonal grain.

The strength properties of the four wing beams were uniform and were about the same as those of average grade of spruce, although the specific gravity ran about 20 per cent higher. The large amount of glue area increases the specific gravity of the wing beams without any corresponding increase in strength.

CONCLUSION.

The wings are structurally satisfactory.

AILERON TEST.

DESCRIPTION.

The MB-6 aileron is unbalanced and of wood construction. The structure is built on a wide box spar having main members of spruce joined with plywood. Between each rib large holes are cut in the plywood in order to lighten the structure.

The ribs have plywood cores and spruce cap strips. The trailing edge is formed by a wire connecting the rib ends.

Weight of aileron	9 pounds.
Area of aileron	7 square feet.
Weight per square foot	1.285 pounds.

Figure 12 is a drawing of the aileron structure.

PROCEDURE.

The aileron was assembled on the wing and the controls connected. A spring balance was coupled to the control stick to measure the pull on the stick. The aileron was then loaded according to the loading schedule in Figure 12.

RESULTS.

The aileron supported an average load of 37.5 pounds per square foot without failure.

CONCLUSION.

The aileron structure and controls are structurally satisfactory, the required load per square foot being 35 pounds.

ELEVATOR AND STABILIZER.

DESCRIPTION.

The elevator and stabilizer are of wood construction. The forward spars of these surfaces are wide box spars with spruce main members joined by plywood. On both the elevator and stabilizer large holes are cut through the plywood between the ribs in order to lighten the structure.

The rear spar of the stabilizer is a spruce member covered with plywood on the top and bottom which helps to tie the rib caps in solidly. To this member are bolted the hinges of the elevator.

The fin is a part of the stabilizer structure.

Figure 13 is a drawing of the stabilizer and elevator structure.

Figure 14 shows typical rib sections and spar sections.

The following is a table of weights and areas of elevator and stabilizer:

	Weight.	Area.	Weight per square foot.
	Pounds.	*Square feet.*	*Pounds.*
Elevator	15.75	14.00	1.125
Stabilizer	10.00	6.54	1.52

The elevator is of the balanced type with cable control.

The stabilizer is mounted on the fuselage and has no adjustment for varying the angle of incidence.

PROCEDURE.

The stabilizer and elevator were mounted on the fuselage as for flight and a spring balance attached to the control stick to register the pull in the cables. The surfaces were then loaded according to the loading schedule in Figure 15.

The center of gravity of the load on the elevator was located at five-twelfths of the chord from the hinge center line, due to the fact that the load at the trailing edge was one-third the load at the hinge center.

RESULTS.

Figure 15 shows the deflections and results of the test. The horizontal tail surface stood the test without signs of failure.

DISCUSSION.

The required load per square foot for the stabilizer and elevator is 35 pounds. At this load the cross member supporting the control stick showed a torsional deflection of one-half inch. It is evident that this member should be heavier.

CONCLUSION.

The horizontal tail surfaces are structurally satisfactory.

RECOMMENDATIONS.

Redesign the cross member supporting the front part of the pilot's seat and the control stick so as to eliminate excessive deflection when tail surfaces are supporting their required load.

RUDDER AND FIN.

DESCRIPTION.

The rudder and fin are of wood construction similar to the horizontal tail surfaces.

The rudder structure has one main box spar whose main members are spruce connected with plywood. To this spar the ribs are attached. The ribs are plywood with spruce cap strips. Midway between the main box spar and the trailing edge is a light spruce spar which adds stiffness to the structure. The trailing edge is a steel wire fastened to the ribs by metal strips nailed to the ribs. The upper and lower end pieces are curved laminated spruce. The rudder is of the balanced type.

The fin, which is built on the stabilizer, consists of a laminated spruce curved top member stiffened by plywood on each side.

Figure 16 is a drawing of the rudder and fin structure.

Figure 17 shows typical sections.

The following is a table of weights and areas of rudder and fin:

	Weight.	Area.	Weight per square foot.
	Pounds.	*Square feet.*	*Pounds.*
Rudder	7.00	5.79	1.21
Fin	1.75	1.88	.93

The rudder is controlled by cable.

PROCEDURE.

The rudder and fin were mounted on the fuselage. The fuselage was turned on its side and the surfaces were then loaded according to the load schedule in Figure 18. A spring balance was coupled in the controls to register the pull in the wires.

The center of gravity of the load on the rudder was located at five-twelfths of the mean chord from the hinge center, due to the fact that the load at the trailing edge was one-third the load at the hinge.

RESULTS.

The required loading for the rudder and fin was 30 pounds per square foot. The surfaces supported an average loading of 40 pounds per square foot without signs of failure.

CONCLUSION.

The rudder and fin are structurally satisfactory.

FUSELAGE.

DESCRIPTION.

The fuselage of the MB-6 is of wood construction with swaged steel brace wires. The fittings are formed sheet steel and of the wrapped type. The upper longerons are laminated white ash as far back as the rear of station 5; from this point rearward the longerons are spruce.

The lower longerons are laminated white ash as far back as the rear of station 3; from this point rearward the longerons are spruce. All the vertical brace members are spruce and are routed T section in shape. The engine bearers are laminated ash and are carried on plywood bulkheads.

Figure 19 is a drawing of the fuselage structure.

PROCEDURE.

The fuselage was supported on a jig in such a manner as to transmit the entire load to the jig through the wing fittings. The structure was loaded as indicated by the loading schedule in Figure 20.

Deflection readings were taken at points along the structure as indicated in Figure 21.

RESULTS

The fuselage structure was required to support a load factor of 7. The engine bearers supported a load factor of 7.5 without any signs of failure. With load factor of 11 on the tail the wires in the fourth bay to the rear of the pilot's cockpit failed.

Figure 21 shows the results of the fuselage test.

Figure 27 is a photograph of the failure.

DISCUSSION.

The longerons showed much distortion and small cracks, developed in them. After the load was removed the longerons showed a permanent set.

CONCLUSION.

The fuselage structure is structurally satisfactory.

LANDING CHASSIS.

DESCRIPTION.

The landing chassis of the MB-6 is of the V strut type, with streamline brace wires and a tubular steel axle. The axle consists of two short tubes hinged at the inner ends and supported at the hinges by vertical streamline tension wires which take the load. The axle assembly is contained in an airfoil which serves as a stiffening member between the struts.

Figure 22 is a drawing of the landing chassis.

PROCEDURE.

The landing chassis was mounted in the test jig in such a manner that the center of gravity of the load was vertically over the center of the axle. The landing chassis was loaded in accordance with the loading schedule in Figure 23. No axle deflections were measured. The only deflection measured was that of the shock absorbers.

RESULTS.

The required load factor for the landing chassis was 6. The chassis supported this load without signs of failure. At a load factor of 8 the right front strut failed.

Figure 23 shows the test results.

Figure 28 is a photograph of the failure.

CONCLUSION.

The landing chassis is structurally satisfactory.

LEADING EDGE TEST.

DESCRIPTION.

A 6-foot section of the upper wing panel was supported along the spar centers on a timber framework. The wing section was loaded from the center line of front spar to the leading edge, a distance of 9 inches. Figure 24 shows the set up.

RESULTS.

At a load of 3,300 pounds the cap strips failed and the leading edge portion broke off at the rear side of the front spar. This tore the front spar from the rest of the wing structure.

Figure 29 shows the nature of the failure.

CONCLUSION.

The leading edge of the MB-6 wing is very satisfactory structurally since the factor of failure was 20.8, the required load factor for this test being 14.

TAIL SKID TEST.

DESCRIPTION.

The fuselage was attached at the front end to a steel column and a load of 234 pounds was placed on the rear of the fuselage over the tail skid. The rear end was so coupled to a hoist that it could be raised to the desired height and dropped.

PROCEDURE AND RESULTS.

The tail skid withstood the first drop which was through a distance of 6 inches. The failure occurred on the next drop which was through a distance of 12 inches. Figure 30 is a photograph of the failure.

DISCUSSION.

No deflection of the shock absorber elastic was noticed during the test.

CONCLUSION.

The tail skid is weak and poorly designed.

RECOMMENDATIONS.

Redesign tail skid and shock absorber to withstand drop test through distance of 36 inches.

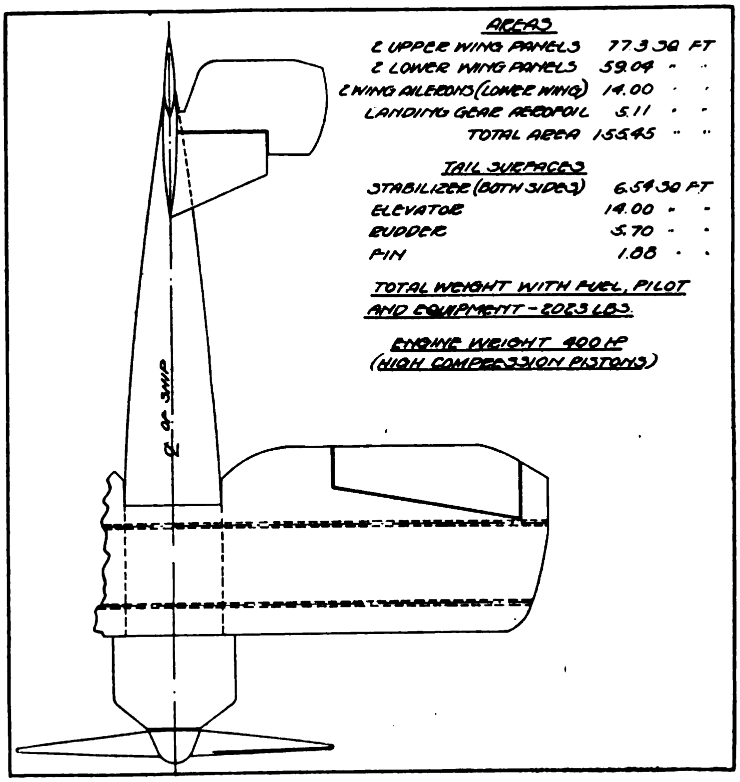


FIG. 1.—Plan view.

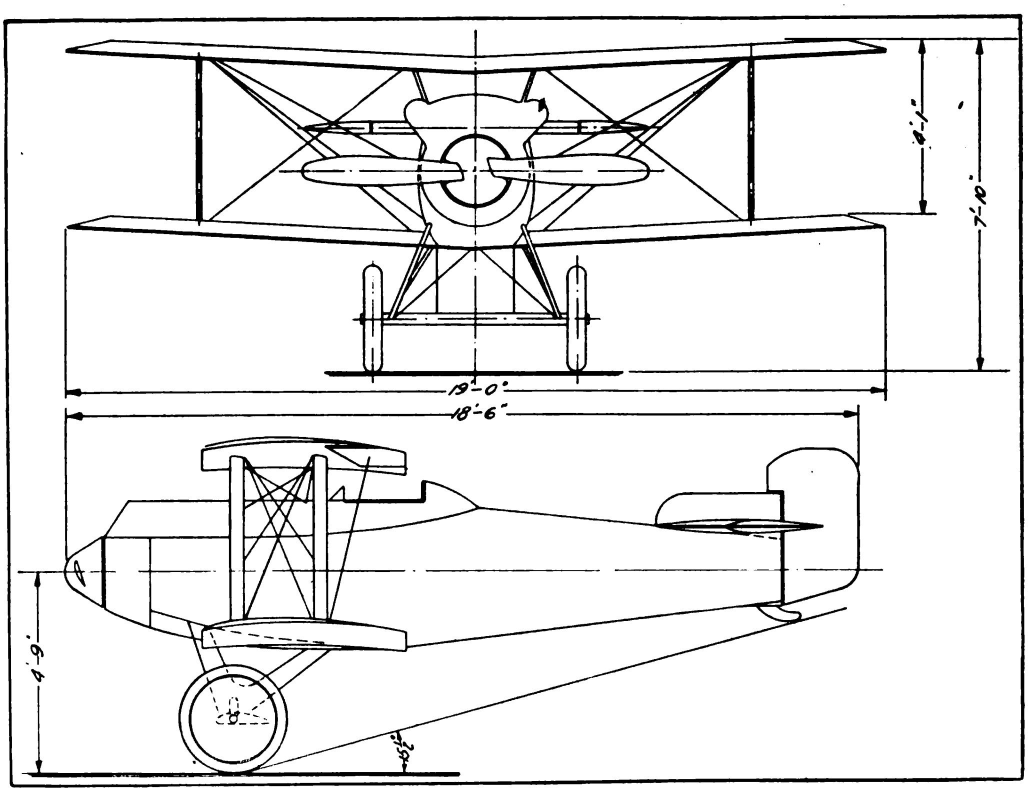


FIG. 2.—Front and side views.

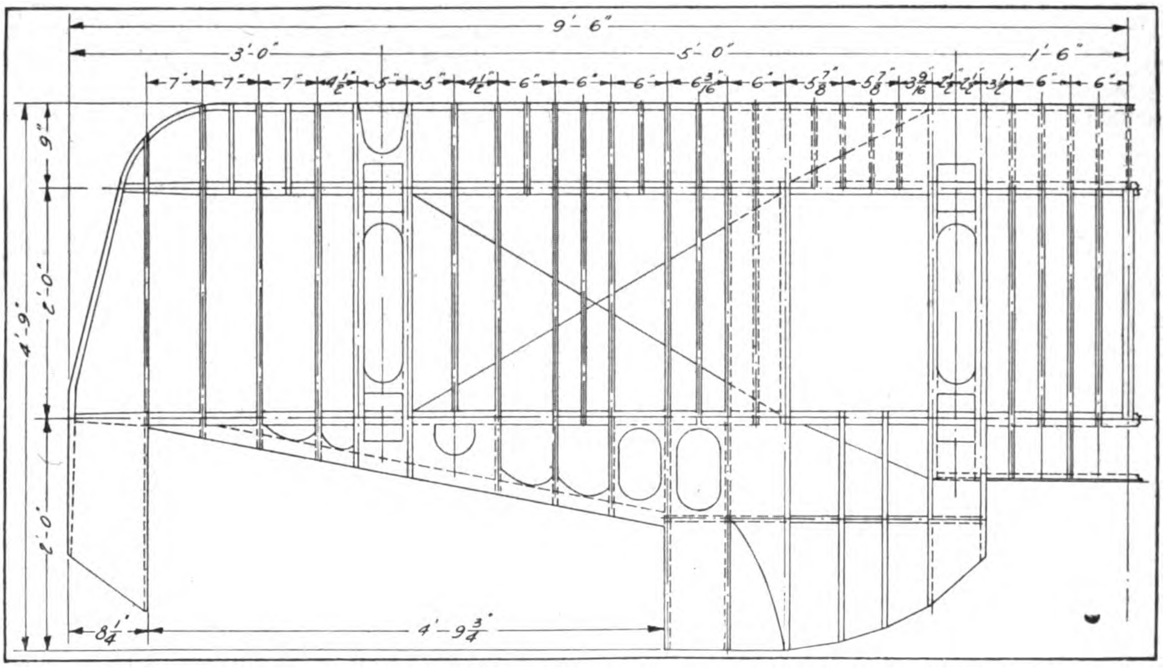


Fig. 3.—Upper wing structure.

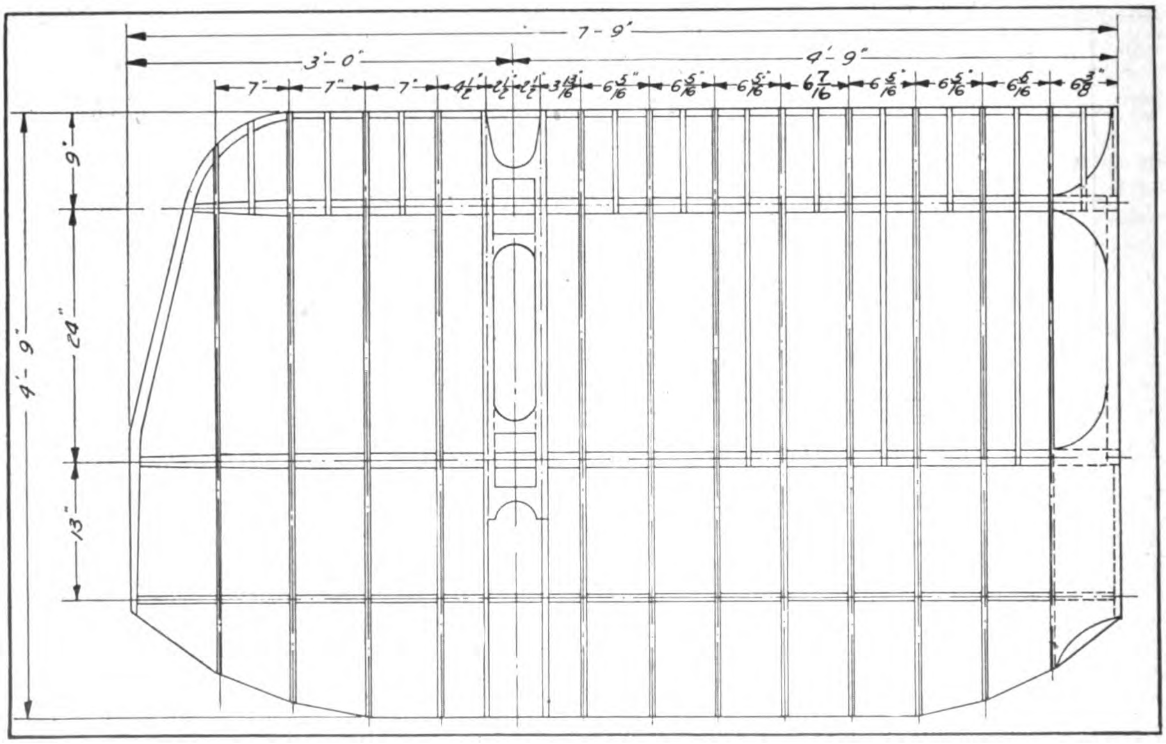


Fig. 4.—Lower wing structure.

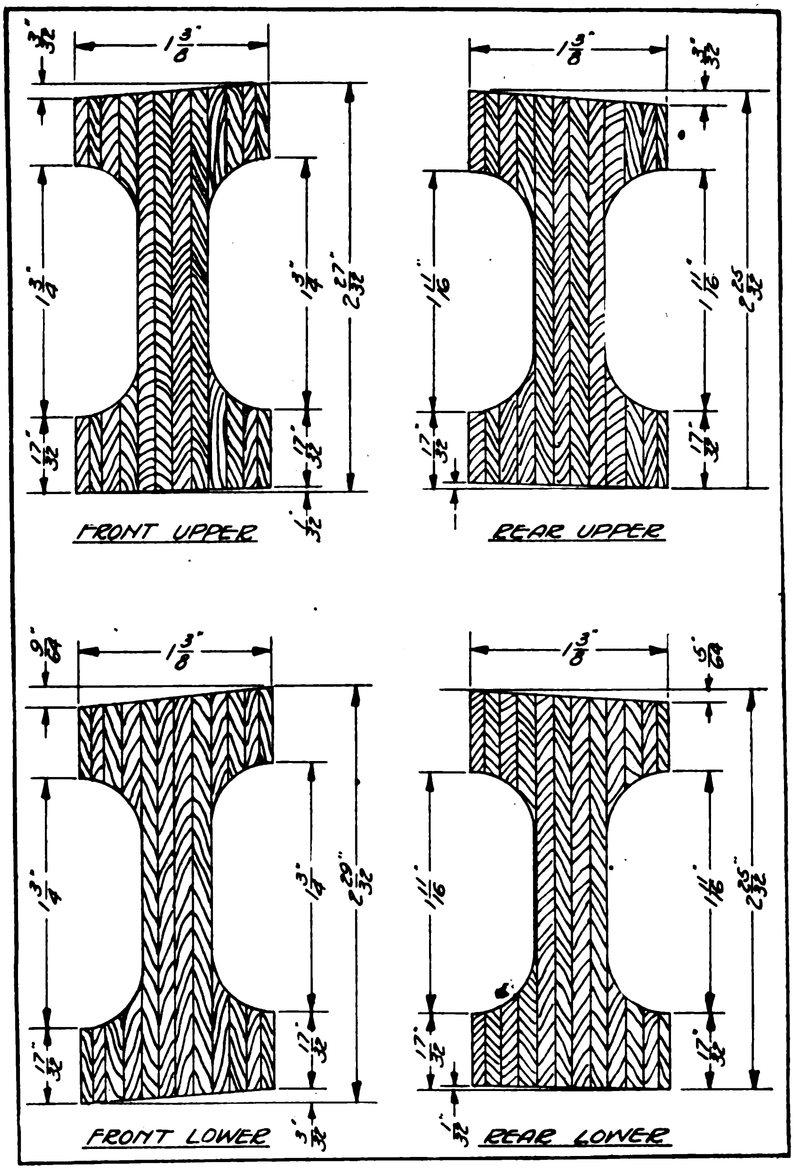
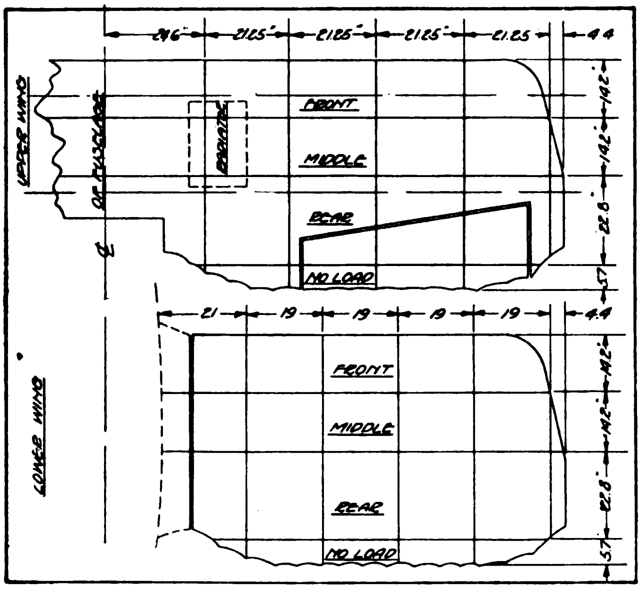


FIG. 5.—Typical spar sections.



LOW INCIDENCE WING LOADING SCHEDULE.

Load factor.	Loads on upper wing.			Total load.	Loads on lower wing.			Total load.
	Front.	Middle.	Rear.		Front.	Middle.	Rear.	
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
2	580	580	580	1,740	520	530	520	1,570
3	800	890	890	2,670	800	810	800	2,430
4	1,200	1,200	1,200	3,600	1,080	1,090	1,080	3,250
4.5	1,360	1,360	1,360	4,080	1,220	1,230	1,220	3,660
5	1,520	1,520	1,520	4,560	1,360	1,370	1,360	4,090
5.5	1,680	1,680	1,680	5,040	1,500	1,510	1,500	4,510

Fig. 6.—Low incidence loading schedule.

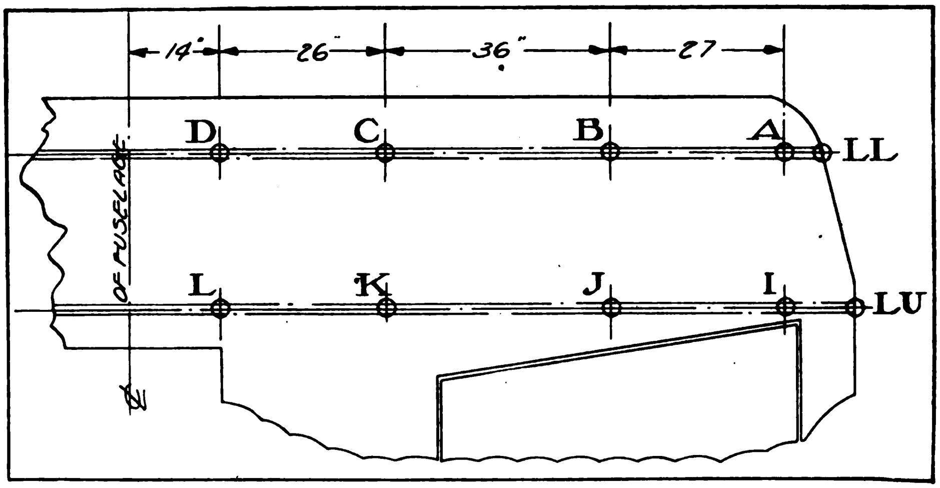


TABLE OF DEFLECTIONS FOR LOW INCIDENCE TEST.

Load factor.	Deflections in inches measured at points.																Retreat.			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	RL	RU	LL	LU
2	.6	.4	.2	.1	.2	.1	.0	.2	.6	.3	.4	.2	.1	.2	.1	.1	0	0	+.3	+.2
3	.7	.5	.3	.1	.2	.2	.1	.3	.8	.6	.5	.2	.2	.3	.2	.4	0	0	+.2	+.5
4	.9	.7	.3	.2	.3	.4	.3	.5	1.0	.6	.7	.3	.2	.3	.4	.6	0	0	+.2	+.5
4.5	−1.1	.7	.3	.2	.3	.4	.3	.6	1.1	.8	.7	.4	.2	.4	.4	.8	0	0	+.2	+.5
5	1.3	.9	.5	.2	.3	.4	.3	.6	1.4	.9	.8	.4	.2	.5	.5	.9	0	+.1	+.2	+.5
5.5	1.5	.9	.5	.4	.4	.5	.4	.7	1.5	.9	.8	.5	.3	.5	.6	1.1	0	+.1	+.2	+.5

Fig. 7.—Deflection chart at low incidence.

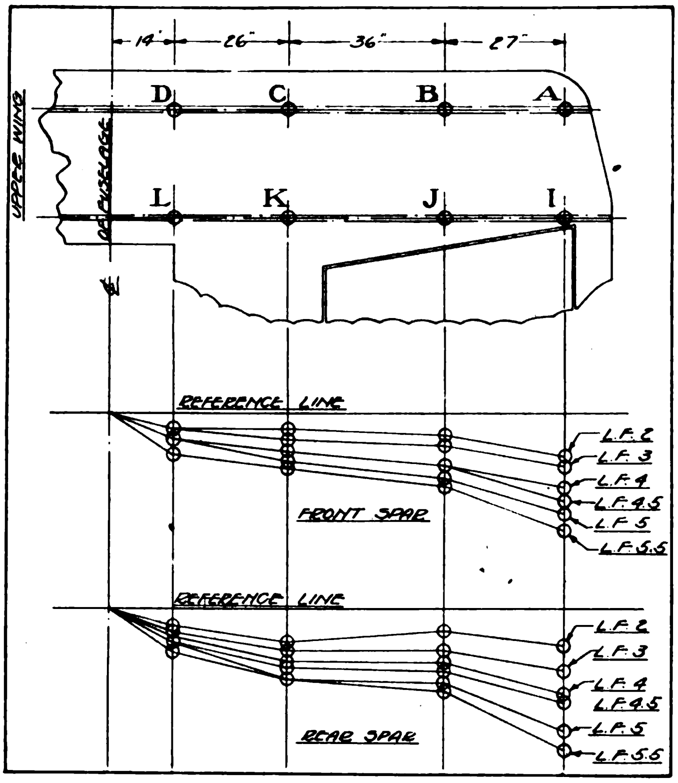
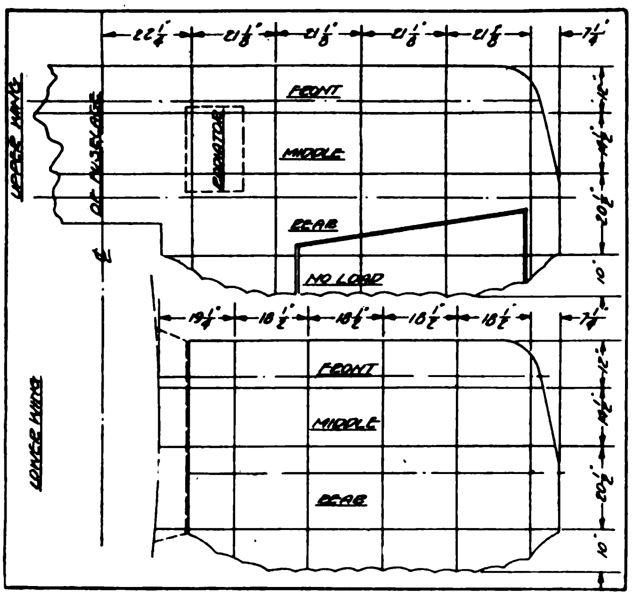


FIG. 8.—Spar deflection curves at low incidence.



HIGH INCIDENCE WING LOADING SCHEDULE.

Load factor.	Loads on upper wing. Front.	Loads on upper wing. Middle.	Loads on upper wing. Rear.	Total load.	Loads on lower wing. Front.	Loads on lower wing. Middle.	Loads on lower wing. Rear.	Total load.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds*	*Pounds.*
3	135	68	68	2,710	119	59	59	2,370
4	182	92	91	3,650	160	80	79	3,190
5	229	116	114	4,590	201	101	99	4,010
6	276	140	137	5,530	242	122	119	4,830
6.5	290	152	149	3,910	263	132	129	5,240
7	314	164	161	6.390	284	142	139	5,650
7.5	338	176	173	6,870	305	152	149	6,060
8	362	188	185	7,350	326	162	159	6,470
8.5	386	200	197	7,830	347	172	169	6,880
9	410	212	209	8,310	368	182	179	7,290

FIG. 9.—High incidence loading schedule.

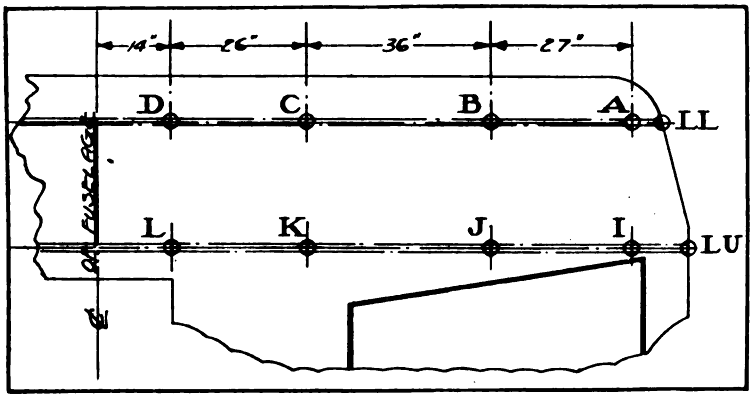


TABLE OF DEFLECTIONS FOR HIGH INCIDENCE TEST.

Load factor.	Deflections in inches measured at points.																Retreat.			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	RL	RU	LL	LU
3	.3	.1	.3	.0	.2	.3	.0	.2	.1	.1	.0	.0	.2	.2	.4	.6	+1	+.2	−.3	−.1
4	.5	.2	.4	.1	.3	.5	.6	1.0	.2	.2	.2	.1	.2	.4	.6	.8	+1	+.2	−.3	−.1
5	.7	.3	.5	.1	.4	.6	.8	1.2	.3	.3	.2	.1	.2	.4	.7	.9	0	+.2	−.4	−.1
6	1.0	.5	.6	.3	.4	.7	.8	1.4	.6	.4	.4	.1	.4	.5	.8	1.1	−.1	+.2	−.4	−.2
6.5	1.3	.6	.7	.3	.4	.7	.9	1.5	.7	.7	.4	.1	.4	.5	.8	1.1	−.1	+.3	−.5	−.2
7	1.4	.7	.8	.3	.4	.7	1.0	1.5	.8	.6	.5	.1	.4	.5	.8	1.2	−.1	+.3	−.5	−.2
7.5	1.5	.8	.9	.3	.4	.8	1.0	1.7	.9	.6	.5	.1	.4	.6	.8	1.2	−.1	+.3	−.5	−.2
8	1.7	1.0	.9	.4	.4	.8	1.1	1.8	1.1	.6	.6	.1	.4	.6	.9	1.4	−.1	+.3	−.5	−.2
8.5	1.9	1.1	1.0	.4	.4	.9	1.2	1.9	1.3	.9	.6	.2	.4	.7	.9	1.4	−.1	+.3	−.5	−.2
9	Failure.																			

Left rear strut fitting bolt sheared first. This caused left rear strut to fail.

FIG. 10.—Deflection chart at high incidence.

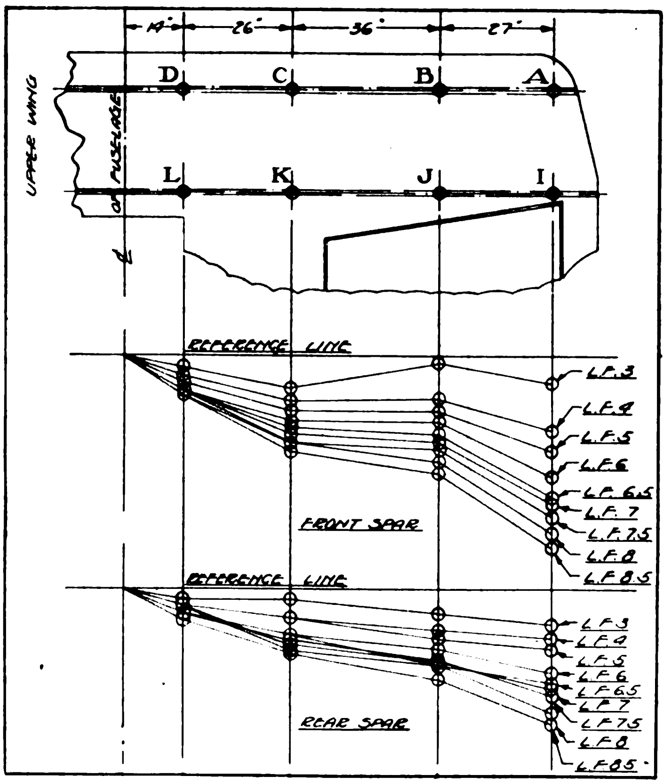
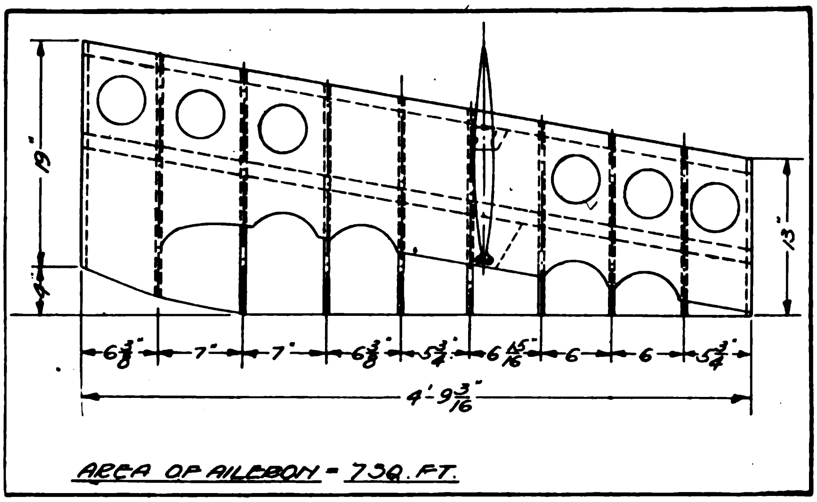


FIG. 11. Spar deflection curves at high incidence.



AILERON LOADING SCHEDULE AND STRUCTURE.

Load in pounds, square feet.	Pull on stick.	Total load on aileron.	Remarks.
	Pounds.	*Pounds.*	
5	15	35	
10	20	70	
15	25	105	
20	35	140	
22.5	45	157.5	
25	55	175.0	
27.5	60	192.5	
30	65	210.0	
32.5	70	227.5	
35	80	245.0	
37.5	85	262.5	Held load without failure.

Fig. 12.—Aileron drawing and loading schedule.

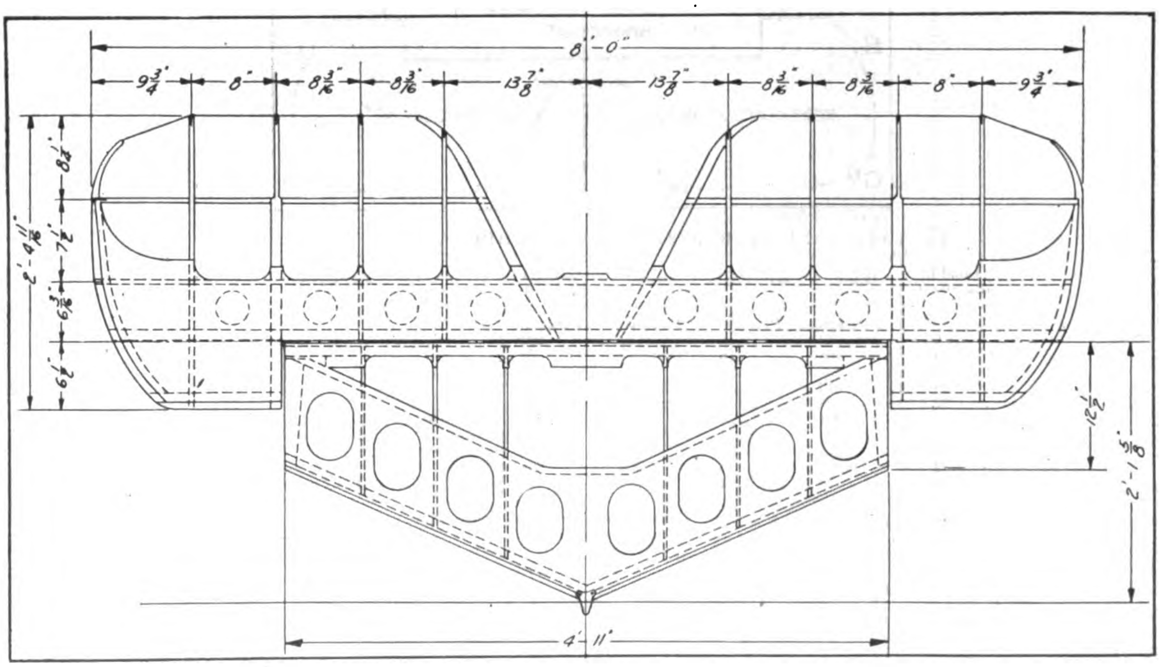


Fig. 13.—Stabilizer and elevator structure drawing.

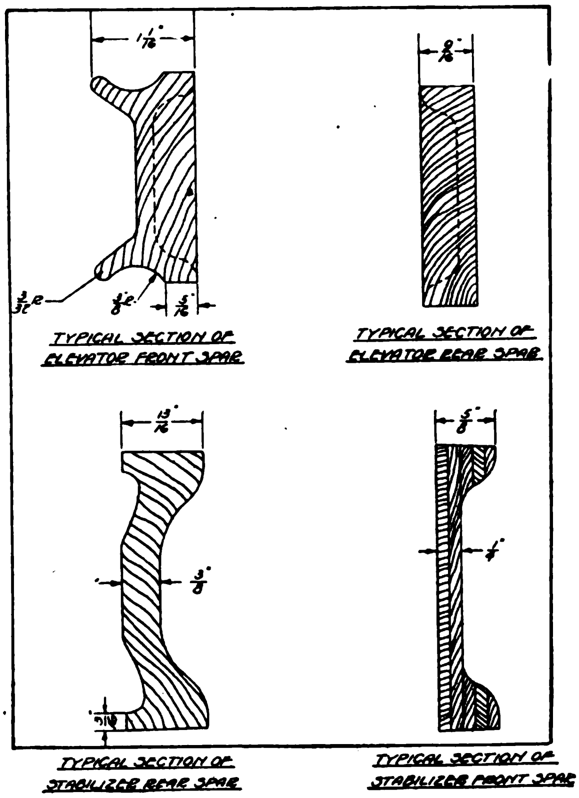
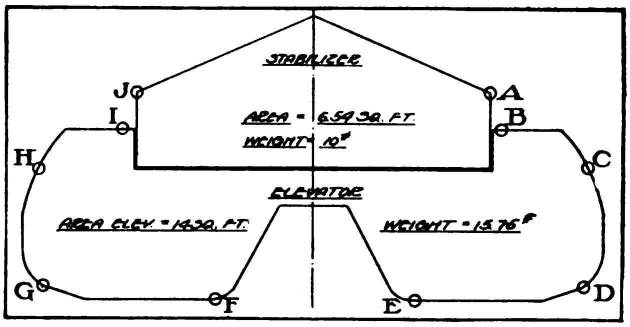


FIG. 14.—Typical sections of stabilizer and elevator.



ELEVATOR AND STABILIZER LOADING SCHEDULE AND TOTAL LOADS.

Load in lbs. sq. ft.	Elev.	Bal. Part.	Stab.	Total load on both.	Remarks.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	
5	52	8	40	100	
10	106	18	82	206	
15	158	26	122	306	
20	212	36	164	414	
22.5	238	40	184	462	
25	264	44	204	512	Stabilizer strut deflected $\frac{1}{16}$ inch.
27.5	290	48	224	562	Stabilizer strut deflected $\frac{1}{16}$ inch.
30	318	54	246	618	Stabilizer strut deflected $\frac{1}{16}$ inch.
32.5	344	58	266	668	Stabilizer strut deflected $\frac{1}{16}$ inch.
35	370	62	286	718	Stabilizer strut deflected $\frac{3}{32}$ inch.

Load in lbs. sq. in.	Pull on stick.	Deflections in inches measured at points.									
		A	B	C	D	E	F	G	H	I	J
5	15	.0	.0	−.1	.1	.0	−.1	.0	.1	.1	.1
10	30	.0	−.2	.0	.7	.6	.5	.6	.2	−.1	.1
15	45	.0	−.4	.1	1.5	1.5	1.4	1.4	.3	−.3	.1
20	65	.0	−.6	.2	2.4	2.2	2.2	2.2	.4	−.5	.1
22.5	75	.1	−.8	.2	2.1	2.9	2.8	2.7	.4	−.7	.1
25	90	.1	−.9	.2	3.3	3.1	3.0	3.0	.5	−.7	.1
27.5	100	.2	−1.0	.2	4.1	3.9	3.8	3.7	.6	−.9	.1
30	110	.2	−1.2	.3	4.6	4.5	4.3	4.2	.6	−1.1	.2
32.5	120	.3	−1.4	.3	5.2	5.0	4.8	4.7	.6	−1.3	.2
35	130	.3	−1.6	.3	7.2	7.0	7.0	9.6	.8	−1.9	.2

FIG. 15.—Loading schedule and results of test of horizontal tail surfaces.

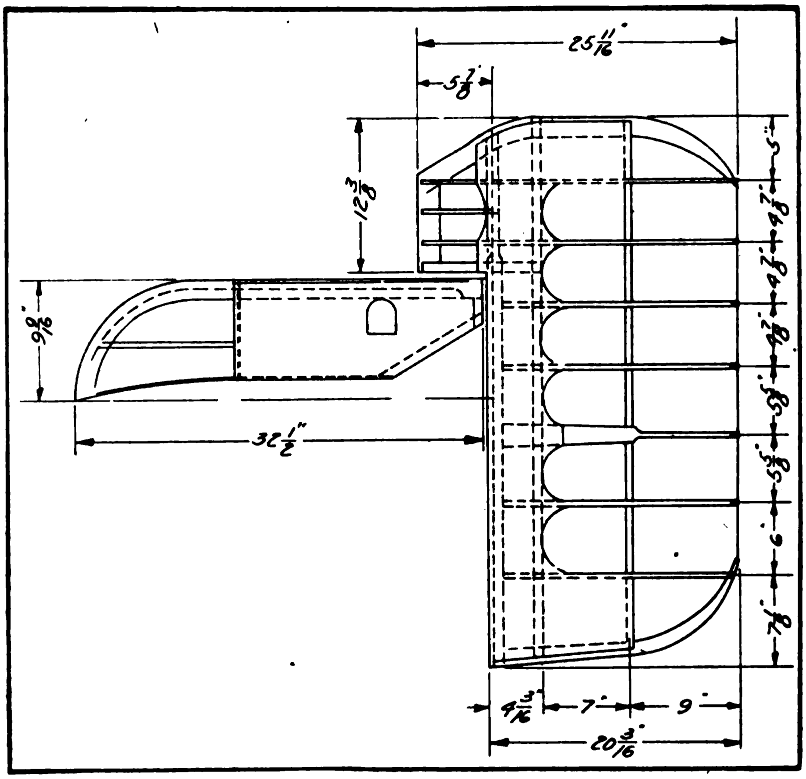


Fig. 16.—Rudder and fin.

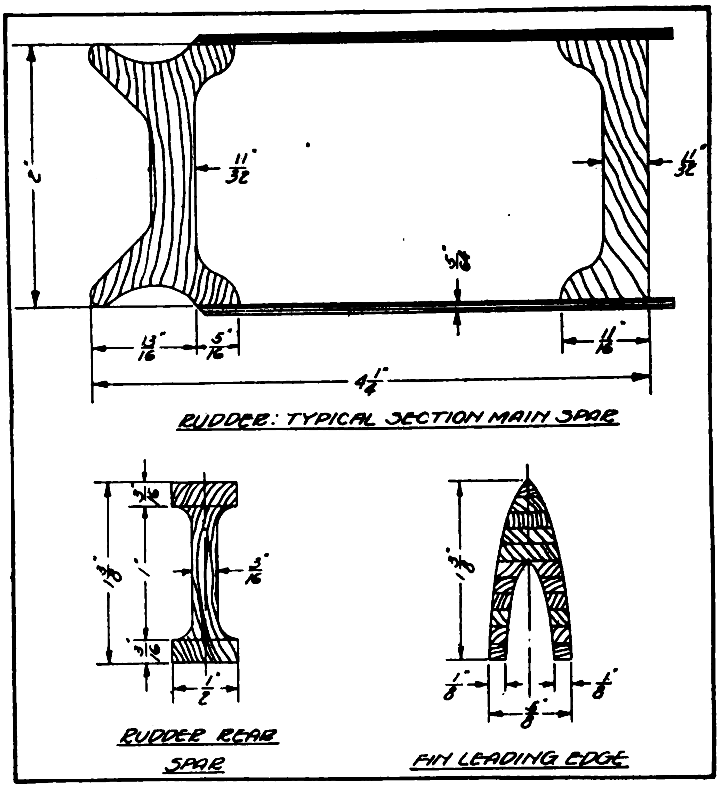
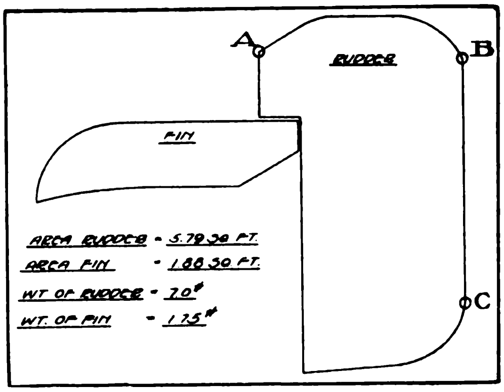


Fig. 17.—Typical sections of rudder and fin.



LOADING SCHEDULE AND RESULTS OF RUDDER AND FIN TEST.

Load factor.	Pull on stick.	Load on rudder.	Load on bal. part.	Load on fin.	Total load on surface.	Deflections in inches at points. A	B	C	Remarks.
Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*				
5	35	24	2	12	38	+0.1	+0.1	−0.1	
10	70	48	4	24	76	.0	.0	+.6	
15	100	72	6	36	114	−.1	1.7	1.2	
20	140	96	8	48	152	−.1	2.0	1.4	
22.5	165	108	8	54	170	−.1	2.0	1.4	
25.0	185	120	10	60	190	−.3	3.0	2.2	
27.5	195	132	10	66	208	−.3	3.2	2.3	
30	210	144	12	72	228	−.4	3.7	2.6	
32.5	255	156	12	78	246	....	....	....	
35	....	168	14	84	266	....	....	....	
37.5	....	180	14	90	284	....	....	....	
40	....	192	16	96	304	....	....	....	Held.

Rudder control wires interfered with diagonal fuselage bracing wires.

FIG. 18.—Loading schedule and results of test of rudder and fin.

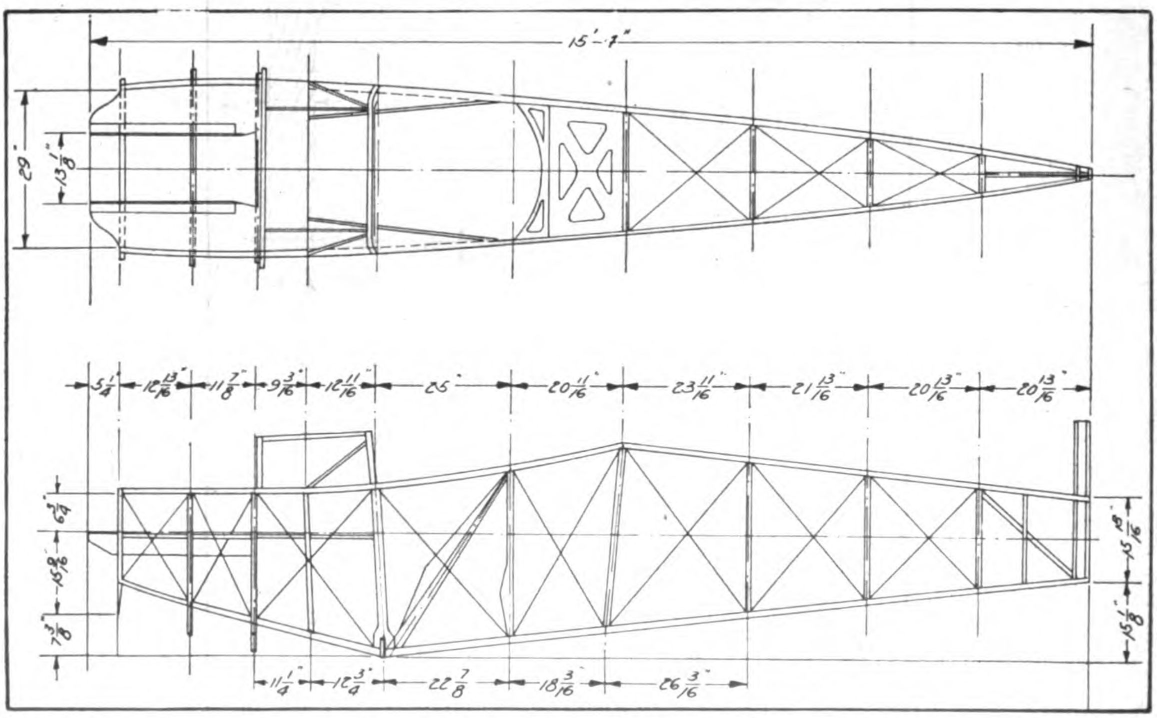
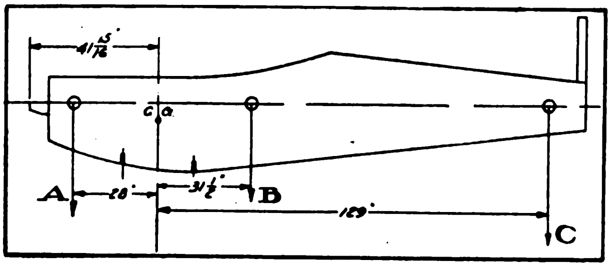


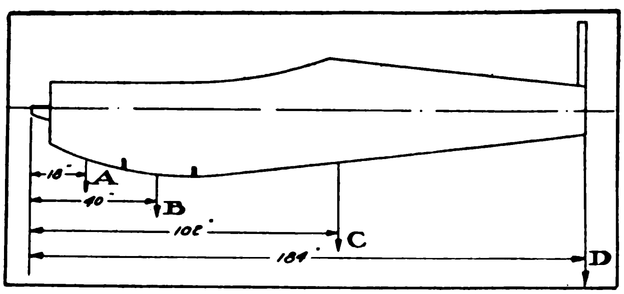
FIG. 19. Fuselage structure.



LOADING SCHEDULE FOR FUSELAGE TEST.

Load factor.	Loads, in pounds, at points—				Total load, in pounds, on structure.	Remarks.
	A	B	C	D		
2	2,000	564	510	329	3,403	
3	3,000	866	795	513	5,174	
4	4,000	1,168	1,080	697	6,945	
5	5,000	1,470	1,365	881	8,716	
5.5	5,500	1,621	1,508	973	9,602	
6	6,000	1,772	1,651	1,065	10,488	
6.5	6,500	1,923	1,794	1,157	11,374	
7	7,000	2,074	1,937	1,249	12,260	
7.5	7,500	2,225	2,080	1,341	13,146	
8	8,000	2,376	2,223	1,433	14,032	
8.5	8,500	2,527	2,366	1,525	14,918	
9	9,000	2,678	2,509	1,617	15,804	
9.5	9,500	2,829	2,652	1,709	16,690	
10	10,000	2,980	2,795	1,801	17,576	
10.5	10,500	3,131	2,938	1,893	18,462	
11	11,000	3,282	3,081	1,985	19,348	
11.5	11,500	3,433	3,224	2,077	20,234	

FIG. 20.—Loading schedule for fuselage.



DEFLECTIONS AND RESULTS OF FUSELAGE TEST.

Load factor.	Deflections, in inches, at—				Remarks.
	A	B	C	D	
2	0.6	0.4	0.1	−1.0	
3	.8	.8	.3	....	
4	1.0	.9	.3	0	
5	1.2	1.0	.4	− .1	
5.5	1.2	1.1	.4	−1.0	
6	1.2	1.2	.6	− .6	
6.5	1.2	1.2	.7	− .6	
7	1.3	1.3	.7	− .6	
7.5	1.4	....	.7	− .6	
8	1.4	....	.7	− .4	
8.5	....	....	....	− .3	
9	....	....	....	+ .1	
9.5	....	....	....	.4	
10	....	....	....	.9	
10.5	....	....	....	1.5	Held.
11	....	....	....	1.8	Failure of right and left brace wires in second bay forward from stern post.
11.5	....	....	....	....	

FIG. 21.—Deflections and results of fuselage test.

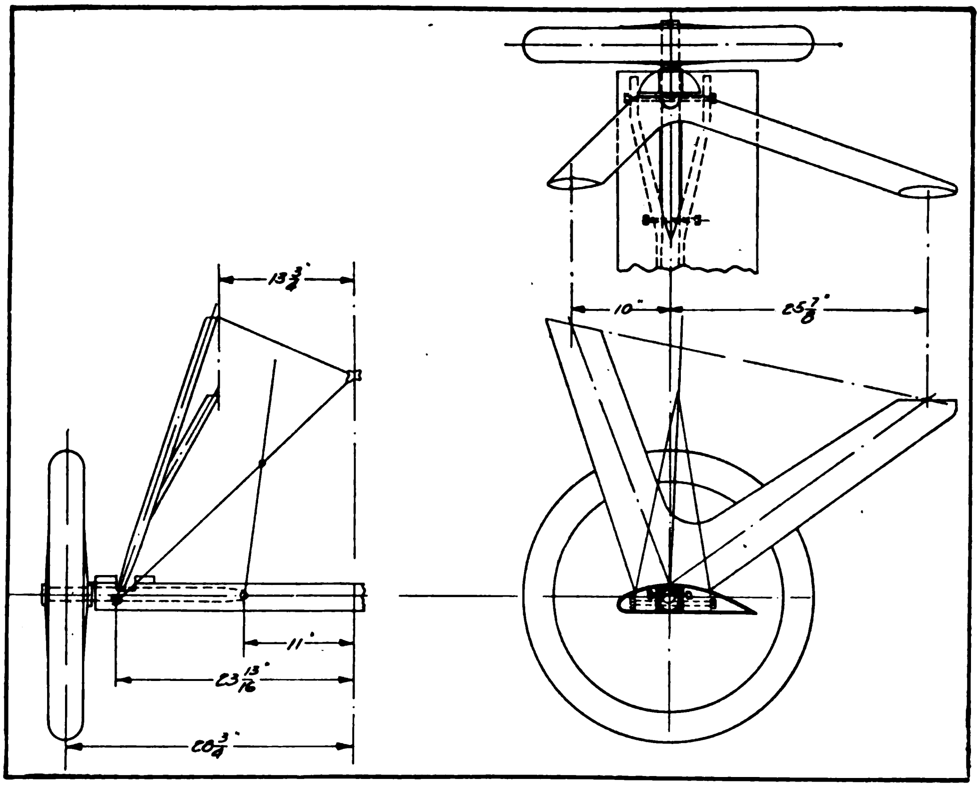
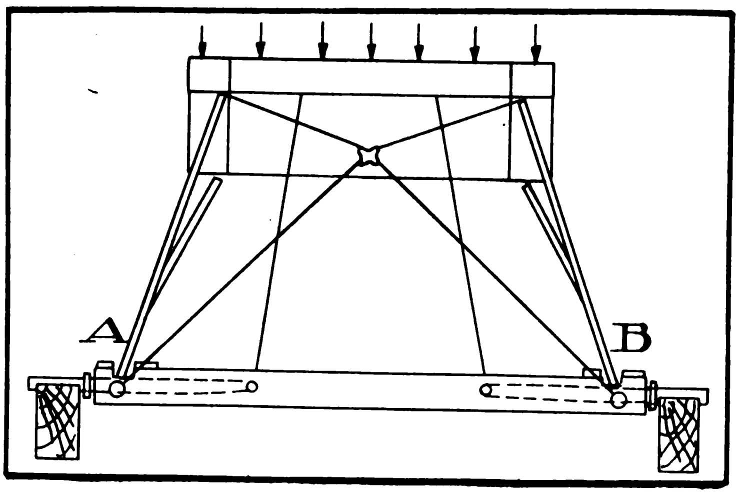


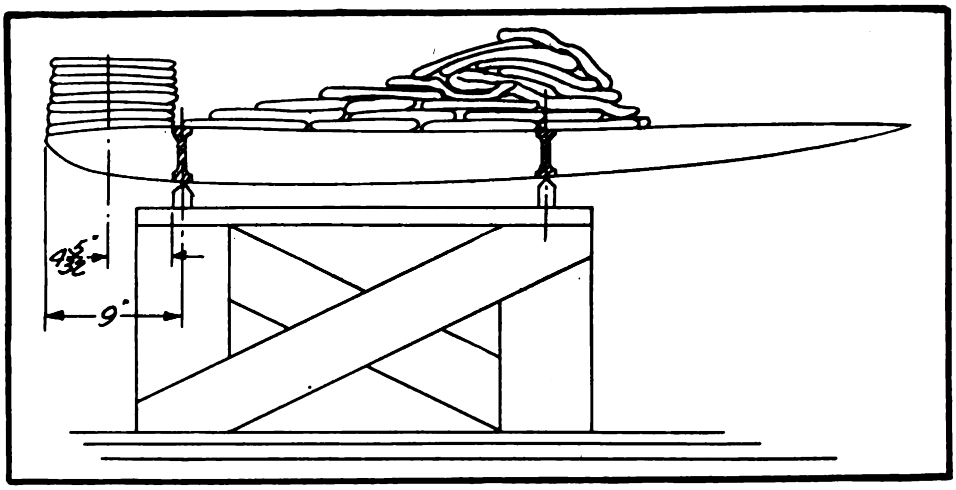
FIG. 22.—Landing chassis.



LOADING SCHEDULE—DEFLECTIONS AND RESULTS OF LANDING CHASSIS TEST.

Load factor.	Deflections, in inches, at—		Total load (pounds).	Remarks.
	A	B		
2	$\frac{1}{4}$	[illegible]	4,046	
3	$\frac{7}{16}$	[illegible]	6,069	
4	[illegible]	[illegible]	8,092	
4.5	[illegible]	[illegible]	9,103.5	
5	[illegible]	1.0	10,115.0	
5.5	[illegible]	$1\frac{1}{16}$	11,126.5	
6	......	......	12,138.0	
6.5	......	......	13,149.5	
7	......	......	14,161.0	
7.5	......	......	15,172.5	
8	......	......	16,184.0	Failure of right front strut.

FIG. 23.—Loading schedule and results of test of landing chassis.



COMPUTATIONS AND DATA ON LEADING EDGE TEST.

Load on MB-6 wings for factor of 1 = 1,807 pounds.
Load on upper wing for factor of 1 = 1,807 × .52 = 939.64 pounds.
Span over which wing was loaded = 17.783 feet.

Load on upper wing per foot run $\frac{939.44}{17.783} = 52.83$ pounds.

Load for factor of 1 on leading edge $= \frac{52.83}{2} = 26.465$ pounds.

Load on leading edge causing failure = 3,300 pounds.

$\frac{3,300}{6} = 550$ pounds = load per foot run causing failure.

$\frac{550}{26.465} = 20.8$ = factor at which leading edge failed.

FIG. 24.—Leading edge test.

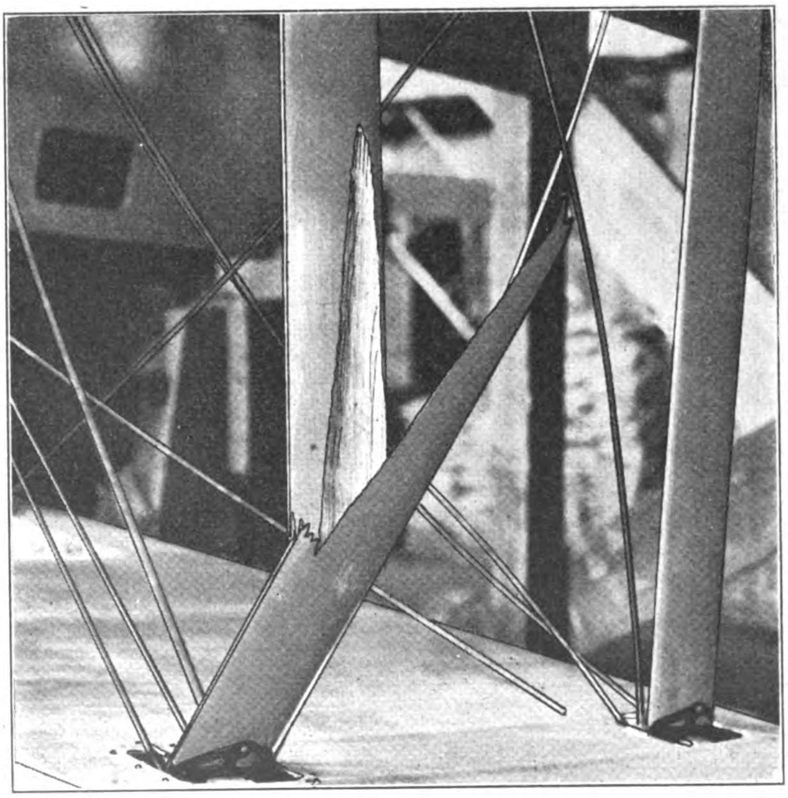


FIG. 25.—Strut failure.

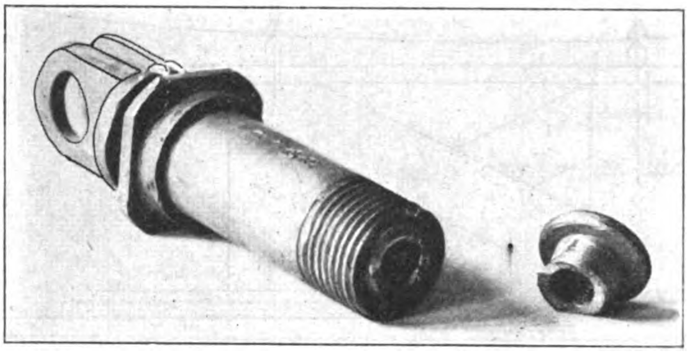


FIG. 26.—Strut fitting bolt.

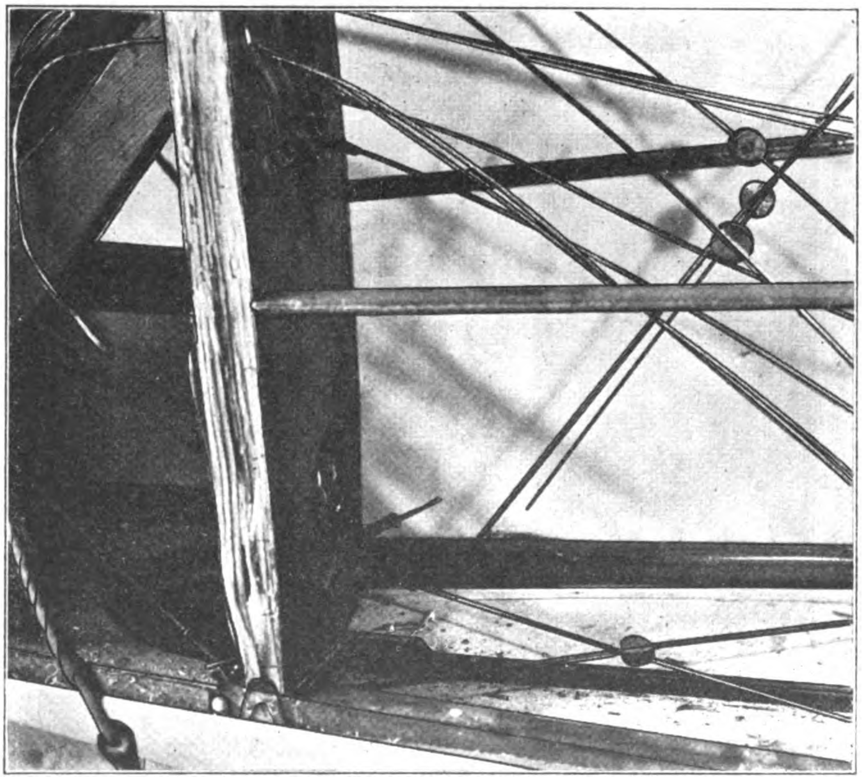


FIG. 27.—Fuselage failure.

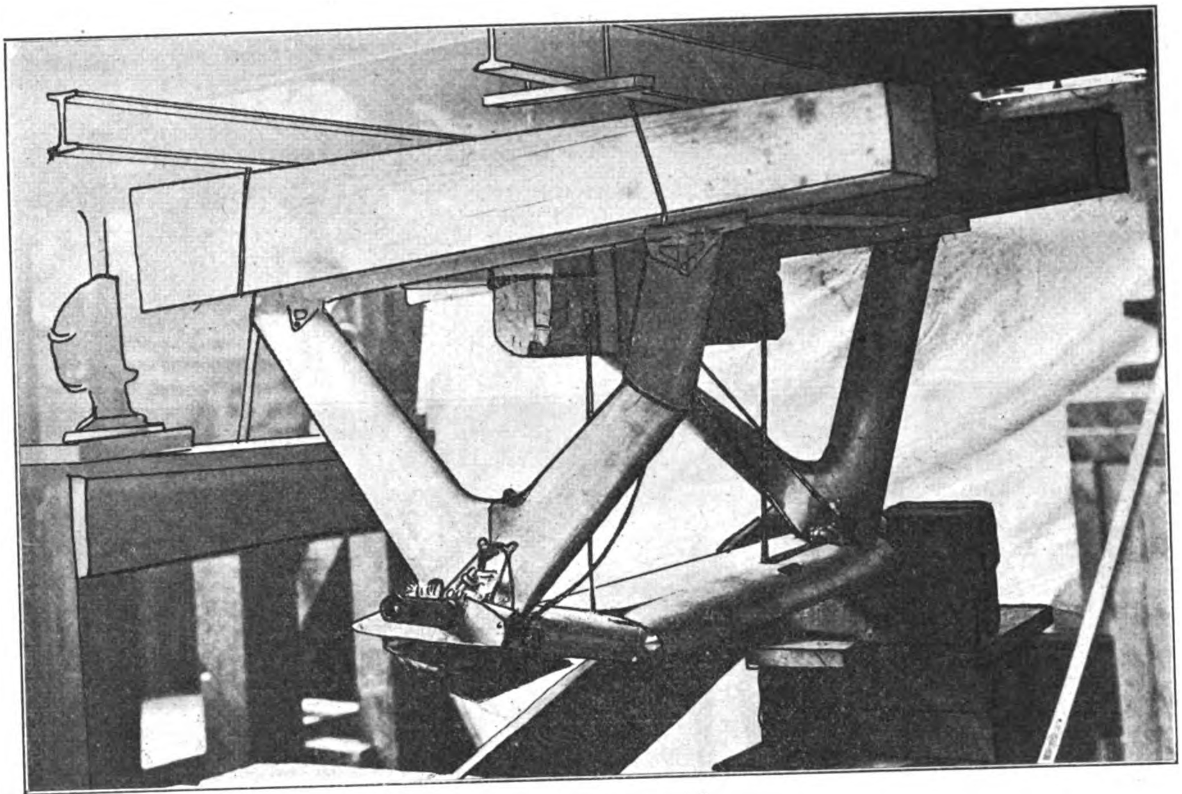


FIG. 28.—Landing chassis failure.

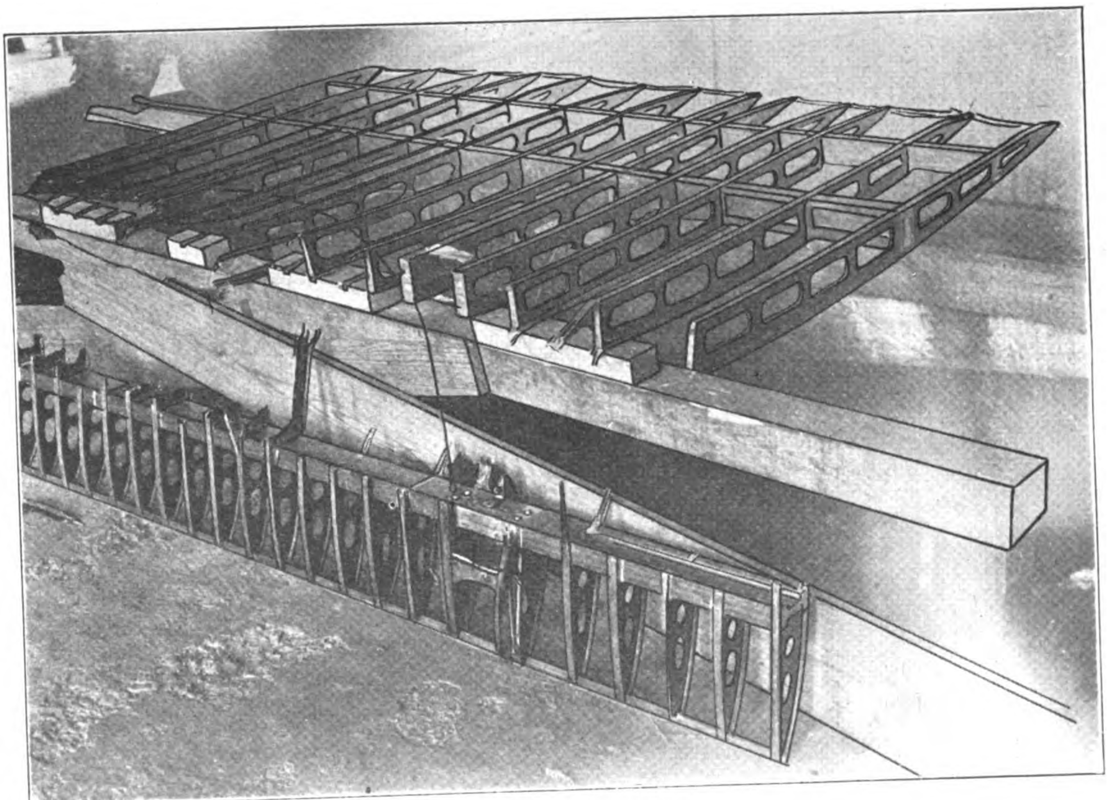


FIG. 29.—Leading edge failure.

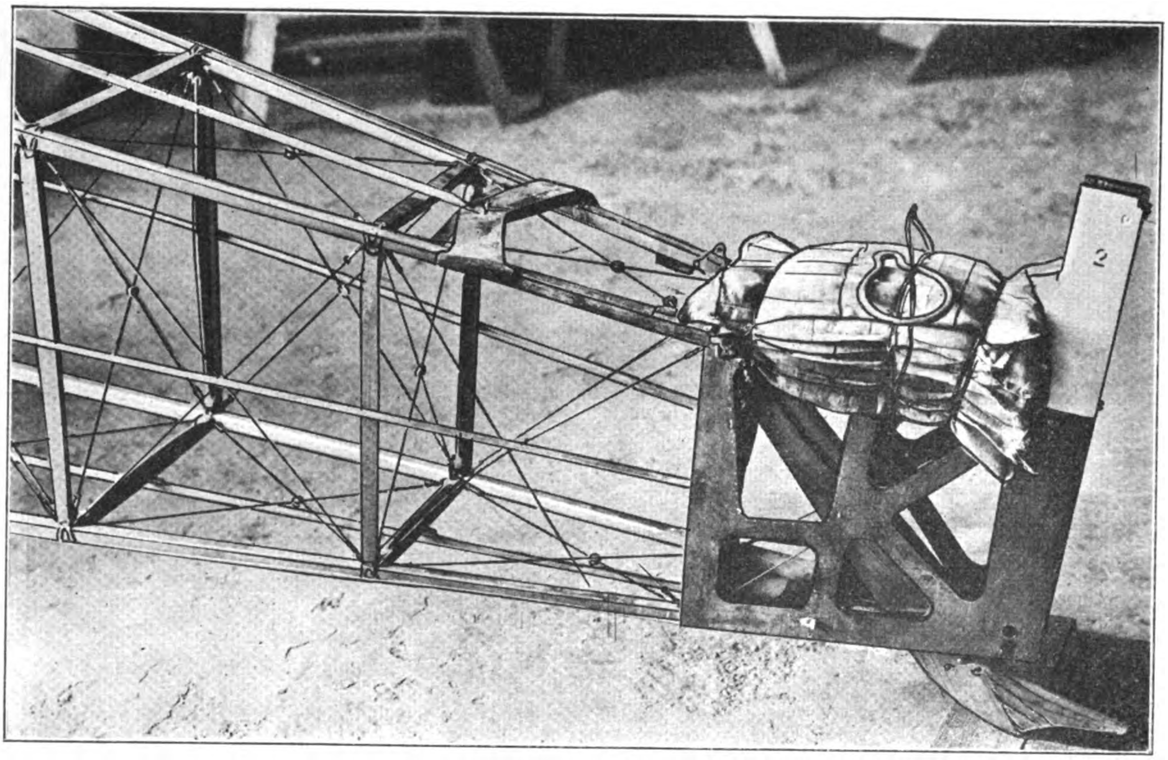


FIG. 30.—Tail skid failure.

File D 50.1/7 McCOOK FIELD REPORT, SERIAL No. 1924

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)
PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV August 15, 1922 No. 363

HEAT TREATING BATH COMPOSED OF SODIUM CHLORIDE, SODIUM CARBONATE, AND SODIUM CYANIDE

(MATERIAL SECTION REPORT No. 166)

▽

Prepared by E. V. Schaal
Engineering Division, Air Service
McCook Field, Dayton, Ohio
May 17, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

HEAT TREATING BATH COMPOSED OF SODIUM CHLORIDE, SODIUM CARBONATE, AND SODIUM CYANIDE.

PURPOSE.

To determine the suitability of a heat-treating bath composed of sodium chloride and sodium carbonate with and without addition of sodium cyanide.

CONCLUSIONS.

A mixture of 40 per cent sodium chloride and 60 per cent sodium carbonate is found to decarburize the steel considerably, but this decarburizing tendency is neutralized by the addition of about 15 per cent of sodium cyanide.

Caution must be exercised in heating the mixture for the first time to avoid "cave-ins" followed by expulsion of the mixture, due to sudden evolution of steam when the unmolten portions fall into the hot liquid.

There is considerable foaming and flaming on the surface of the bath after adding the cyanide, but this phenomenon subsides after the bath has been held in the vicinity of 1,400° F. for six or eight hours.

A bath consisting of 35 per cent NaCl, 52 per cent Na_2CO_3, and 13 per cent NaCN gave satisfactory results for heat-treating parts where sealing must be reduced to a minimum and where the temperature used ranges between 1,200° and 1,600° F.

MATERIAL.

120 lbs. sodium carbonate (commercial).
80 lbs. sodium chloride (commercial).
20 lbs. sodium cyanide (commercial).
2 rods about 6 inches long of 1045 steel.
2 rods about 6 inches long of drill steel (hypereutectoid).

PROCEDURE.

The furnace used for this investigation is one formerly used as a lead pot. The pot, which is made of cast iron, is about 20 inches in diameter and 16 or 18 inches in depth.

In order to melt the sodium carbonate and chloride they were mixed in the proportion of 40 parts of chloride to 60 parts of carbonate (anhydrous) and the pot was filled, when cold, with this mixture. The furnace was then fired. It was soon observed that when any of the unfused material fell into the molten part there was a sudden evolution of steam and mixture from the pot. On one occasion so much unfused material caved in that an explosion resulted in which fully half of the contents of the pot, molten and otherwise, were expelled over a radius of about 10 feet. After this experience, only small amounts were added at a time until enough of the molten material was obtained. After having been once melted, no trouble was experienced in remelting.

Before adding the cyanide, one specimen of 1045 steel was treated at 1,600° F. for one hour and one of drill steel was treated at 1,425° F. for one hour, both treatments being followed by water quenching. The 1045 steel was represented as 1020 steel, which accounts for the high temperature used in treating it.

The surface condition of these specimens was noted after the treatment, and transverse sections were prepared in the usual manner for microscopic examination. Photomicrographs were taken of these sections, as shown in Figures 1, 3, and 5.

A record was kept of the amount of carbonate and chloride used in making up the original bath, but inasmuch as part of what had been weighed was lost by the explosion, an estimate had to be made of the quantity remaining in order to compute the 15 per cent of cyanide which was to be added. This was done as carefully as possible, but it leaves some doubt as to the exact proportions actually used. This is thought to be of no great importance, however, as long as the proportions are within 2 or 3 per cent of those desired.

The cyanide was added when the bath was frozen and the furnace was slowly brought up to the melting temperature (about 1,200° F.). By heating slowly, the moisture contained in the cyanide eggs was driven off without violence and resultant damage. As soon as the mixture was melted, after adding the cyanide, it began to evolve an inflammable gas which burned on the surface with a characteristic sodium flame color. This color of the flame need not be directly attributed to the gas that was burning, since the evolution of the gas caused fine particles of the sodium salts to be thrown into the air in a sort of mist in in which the gas burned. A rough chemical analysis made on powder deposited on articles in the vicinity of the furnace during this period showed that it contained chloride and carbonate of sodium.

Continued heating above 1,400° F. for seven or eight hours caused the evolution of gas to stop, and after that, the other two steel specimens were treated for one hour each in the same manner as the first ones had been treated. After surface examination they were also sectioned and prepared for microscopic examination. Photomicrographs, Figures 2, 4, and 6, were taken of these specimens.

The temperature of the bath was determined by means of a chromel-alumel thermocouple incased in a chromel tube, and connected to a permanently installed recording potentiometer.

A sort of slag occurred on the surface of the bath after the cyanide was added, but this stopped forming in the course of 10 or 12 hours' heating. This slag was easily removed.

RESULTS.

SURFACE CONDITION OF SPECIMENS.

Specimen No. 1, which consisted of a plain carbon hypereutectoid steel, after having been held in the bath without cyanide for one hour at 1,425° F. and water quenched, had a uniform light-gray appearance except at a few places which were slightly mottled with a darker shade.

Specimen No. 3 (1045 steel), which was held for one hour at 1,600° F. in the same bath as specimen No. 1 and water quenched, had a dark-gray coating over it which could be chipped off by pounding with a hammer. The surface of the steel beneath the coating was bright and smooth.

Specimen No. 2 (plain carbon, hypereutectoid), which was held in the bath (after adding cyanide) for one hour at 1,425° F. and water quenched, possessed a smooth mottled surface similar to that ordinarily obtained from cyanide hardening.

Specimen No. 4 (1045 steel), which was held at 1,600° F. for one hour in the same bath as specimen No. 2 and water quenched, had the same surface appearance as the latter—that is, smooth and mottled.

METALLOGRAPHIC EXAMINATION.

The four specimens were examined in the quenched condition and photomicrographs were taken of each in the center and at the edge. Of these only two are shown (Figs. 5 and 6). In order to more carefully study the surface effects of the heat-treating bath, sections cut from each of the same specimens were all sealed in a heat-treating box to prevent scaling, and heated to 1,500°, followed by cooling in the furnace. These sections were then mounted and polished and the photomicrographs of Figures 1, 2, 3, and 4 were taken at the edges to show the surface effects. A description of these potomicrographs follows:

Fig. No.	Spec. No.	Mag.	Remarks.
1	1	100	Without cyanide. Decarburized to 0.006 inch depth. Drill steel.
2	2	100	With cyanide. Very slight decarburization; about 0.002 inch depth. Drill steel.
3	3	100	Without cyanide. Decarburized to 0.006 inch depth. 1045 steel
4	4	100	With cyanide. Very slight carburization on surface. 1045 steel.
5	3	500	1045 steel, water quenched from 1,600°. Troosto-martensitic structure (troostite dark).
6	2	500	Drill steel, water quenched from 1,425°. Spheroidized cementite in martensitic matrix.

DISCUSSION OF RESULTS.

The relatively long period through which the specimens were held in the bath (one hour) is about five to ten times as long as would be required during actual heat-treating practice. Reducing the time of immersion will proportionately reduce the depth of surface effect from the bath. With this consideration, the effect of the bath with 15 per cent cyanide upon the two grades of steel used in this investigation would be negligible and far below that of any ordinary method of treatment. The surface of the treated part is such that for many purposes, such as tools, the finishing could be done before treatment, barring, of course, cases where warpage might make final machining necessary after treatment.

The fact that the 0.45 carbon steel was slightly carburized on the surface by the bath after cyanide was added, while the high carbon steel was slightly decarburized in the same bath, suggests that the carburizing action would be nil on a steel of intermediate carbon content (0.80 to 0.90 per cent). For any particular grade of steel a cyanide content in the bath could no doubt be arrived at, which would have a neutral effect upon the carbon of the steel.

The slag which rose to the top of the bath after the addition of cyanide may be due to attack of the mixture upon the cast-iron pot or upon some traces of lead still remaining in the pot from its previous use as a lead pot. Since the formation of slag appeared to cease completely, no attempt was made to discover its exact identity.

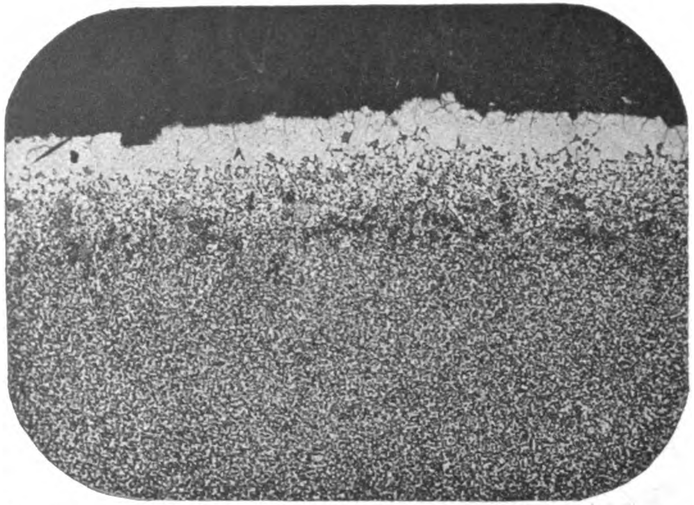


FIG. 677-1.—Magnification, 100 diameters. Etching, nitro-picric acid. Remarks: Specimen No. 1. Hyper-eutectoid steel; held one hour at 1425° F. in bath without cyanide; then furnace cooled from 1500° F. Decarburized edge at top of photograph.

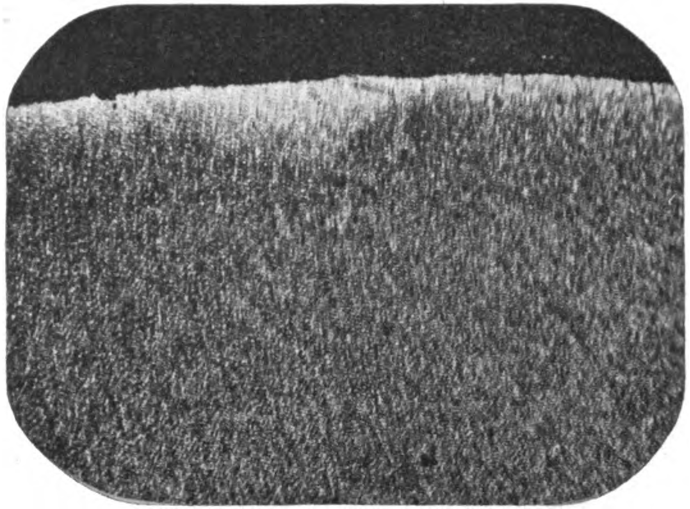


FIG. 677-2.—Magnification, 100 diameters. Etching, nitro-picric acid. Remarks: Specimen No. 2. Hyper-eutectoid steel; held one hour at 1425° F. in bath with cyanide; then furnace cooled from 1500° F. Edge (top) only slightly decarburized.

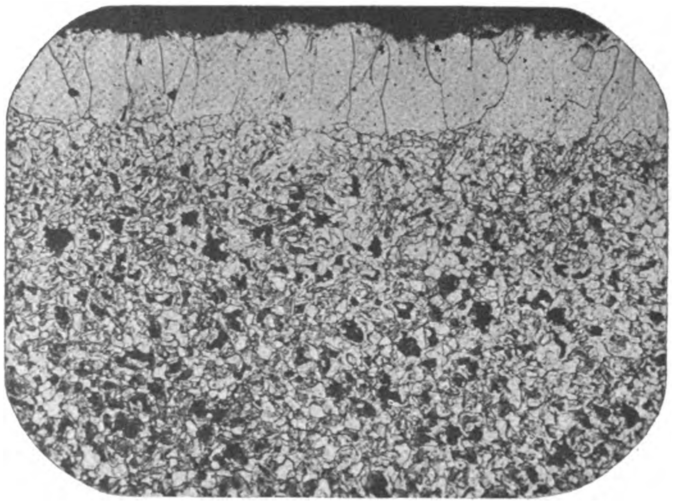


FIG. 677-3.—Magnification, 100 diameters. Etching, nitro-picric acid. Remarks: Specimen No. 3. 1045 steel; held one hour at 1600°F. in bath without cyanide, then furnace cooled from 1500° F. Decarburized edge at top of photograph.

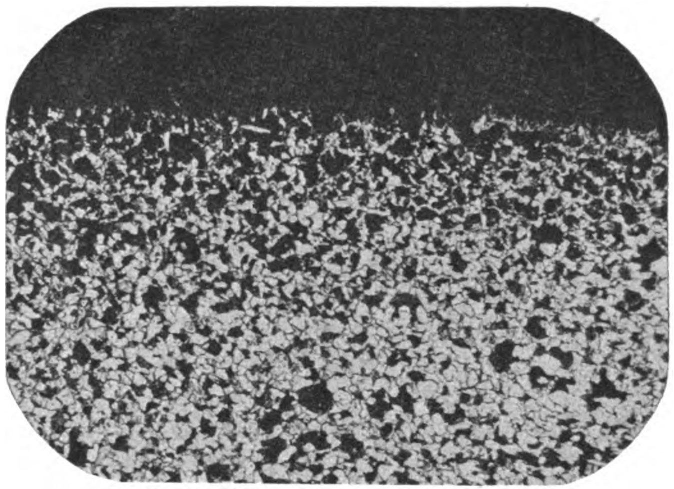


FIG. 677-4.—Magnification, 100 diameters. Etching, nitro-picric acid. Remarks: Specimen No. 4. 1045 steel; held one hour at 1600° F. in bath with cyanide: then furnace cooled from 1500° F. Edge of specimen (top) slightly carburized.

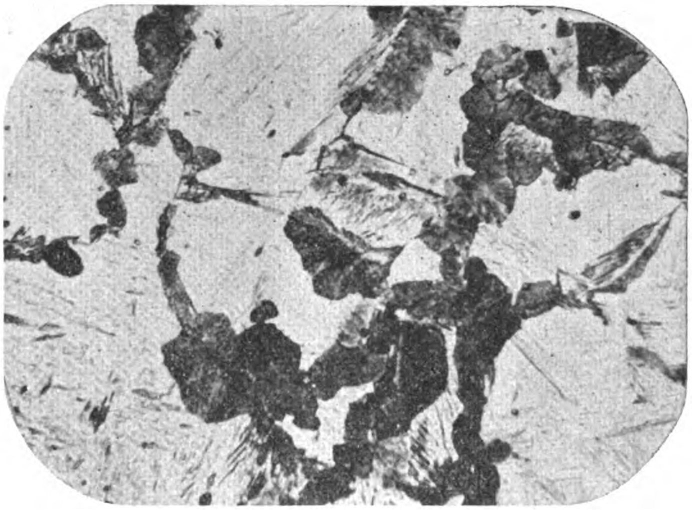


FIG. 677-5.—Magnification, 500 diameters. Etching, nitro-picric acid. Remarks: Specimen No. 3. 1045 steel after quench from 1600° F. Troosto-martensitic structure.

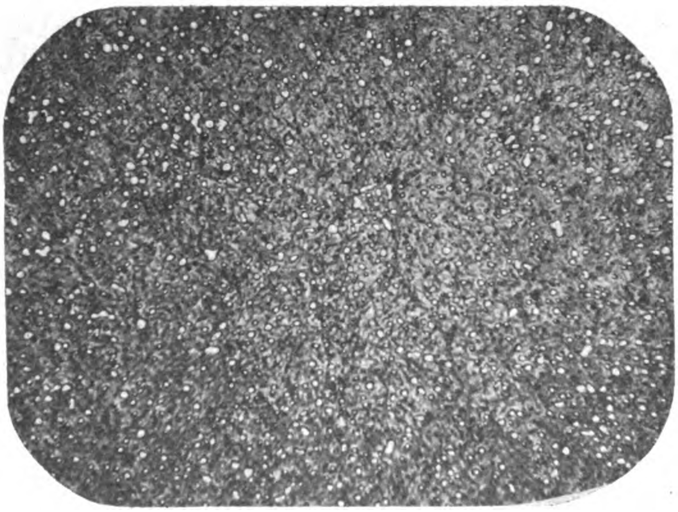


FIG. 677-6.—Magnification, 500 diameters. Etching, nitro-picric acid. Remarks: Specimen No. 2 after quench from 1425° F. Martensitic matrix with pro-eutectoid cementite spheroidized (white).

File D 00.57/2 *McCOOK FIELD REPORT, SERIAL No. 1925*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV August 15, 1922 No. 364

ADAPTABILITY OF THE HYDE WELDING PROCESS TO STEEL ENGINE CYLINDER CONSTRUCTION

(MATERIAL SECTION REPORT No. 165)

▽

Prepared by E. V. Schaal
Engineering Division, Air Service
McCook Field, Dayton, Ohio
May 13, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

ADAPTABILITY OF THE HYDE WELDING PROCESS TO STEEL ENGINE CYLINDER CONSTRUCTION.

PURPOSE.

To determine the feasibility of the Hyde welding process and its effect upon the structures of 1020 and 1045 steel, with a view toward adoption of the process for engine cylinder construction.

CONCLUSIONS.

The welding action is satisfactory as regards formation of a uniform bond and effect upon the structure of the steel.

As compared with other methods of joining steel for high strength, such as torch and arc welding or torch brazing, the Hyde process has some distinct advantages, among which are:

(*a*) Absence of local overheating.

(*b*) More uniform joint.

(*c*) Freedom from warpage due to localized heating or nonuniform cooling.

MATERIAL.

Two steel specimens, each consisting of a section of tubing, about 1 inch in diameter and five-eighths inch long, into which was inserted a plug of the same kind of steel. One specimen was made of 1020 steel while the other was of 1045 steel. The first had the plug fitted tight into the tube, but the latter had a clearance of about 0.004 inch between the diameter of the plug and the tube. The plug protruded above the tube section about one-quarter inch on each specimen. Around the projecting portion of the plug a piece of No. 14 copper wire was wrapped in two complete turns.

ADDITIONAL APPARATUS.

A platinum wound tubular furnace with an inside tube diameter of 1½ inches.

A potentiometer equipped with a platinum-rhodium couple inserted in one end of the furnace inside a porcelain protection tube, the latter being sealed in the end of the furnace with fire clay, together with a one-eighth inch drawn quartz outlet tube.

A tank of compressed hydrogen with reducing valve and connecting tube.

PROCEDURE.

The specimen to be welded was inserted in the furnace to approximately the middle of the tube and very near the end of the thermocouple, the position of the specimen being such that the principal axis of the specimen was vertical and the copper wire was above the section of tubing. After inserting the specimen the end of the furnace was sealed with a plug of fire clay, through which was inserted a tube to admit the hydrogen gas. A very slow stream of hydrogen was then passed through the furnace and ignited at the end of the outlet tube after it had been flowing long enough to exhaust all the oxygen from the interior of the furnace. The furnace was then heated to approximately 2,100° F. and held for 15 minutes, care being taken to keep a steady but slow stream of hydrogen flowing and burning at the outlet continually.

The furnace was allowed to cool down with the hydrogen still flowing. When cold, the plug was removed from the end of the furnace and the specimen withdrawn.

Both specimens were sectioned and polished for microscopic examination, and photomicrographs were taken showing the bond at the weld and the grain size of the steel. One-half of the 1045 steel specimen was annealed at 1,500° F. to determine the effect upon the grain size.

RESULTS.

Both specimens were completely covered with a film of copper which showed evidence of having "wet" the steel perfectly, covering parts of the specimen that were above the original position of the copper wire.

The bond between the copper and steel is clearly shown in Figures 1 to 5, inclusive. The specimens were etched with a concentrated solution of picric acid in alcohol, to which a few drops of nitric acid were added. Figures 1 and 2, at 100 and 500 diameters, respectively, show the effect of the welding upon the 1020 steel.

The grain size has not been seriously enlarged, and the diffusion of the copper into the steel forming an intimate bond is clearly evident, the copper-rich ferrite areas etching darker than other portions and distinctly brown in color.

Figures 3 and 4 show the enlarged grains produced by heating the 1045 steel to 2,100° F. That this overheating has not been serious is demonstrated by Figure 5, which shows the same specimen after heating to 1,500° F. and furnace cooling. The regeneration has been complete and the joint has not been injured.

DISCUSSION OF RESULTS.

While the tests just indicated have not demonstrated all that might be encountered in the welding of engine cylinders by this method, they do give the effects upon the structures of two grades of steel (1020 and 1045). Besides the effects upon the structure of the steel, the extreme uniformity of the joints produced by this process is not only interesting but valuable. From work previously done by this section on brazing it is reasonable to expect that a Hyde welded joint will have the same strength in shear and tension as copper itself. Great uniformity can be expected in joints of this kind because the fluxing is perfect, even on rusty parts. The action of the hydrogen at that temperature (2,100° F.) in the absence of any other

gases quickly reduces all oxides and permits the molten copper to flow into the thinnest crevice.

When welding 1045 steel for any structural purposes, the regenerative heating would be essential. This could be accomplished before removing the work from the welding furnace and without danger of warpage. The operations would be as follows:

(1) Heat to 2,100° F. for welding and allow to cool to 1,000° F.

(2) Heat to 1,500° F. and allow to cool to room temperature.

(3) Remove from furnace.

If a surface entirely free from scale were required on the work, hydrogen could be used throughout the first two operations, but for most work the hydrogen would be turned off, for the sake of economy, after the first operation.

There is probably a large field for this method of joining complex structural parts in airplane construction, not only on the engines but also on fittings. More experimental work must be done before it could be adopted for parts that are to be reheated and quenched, since the effect upon the joint of quenching is yet unknown.

For an account of the origin and use of the Hyde welding process in England see "Engineering," September 2, 1921.

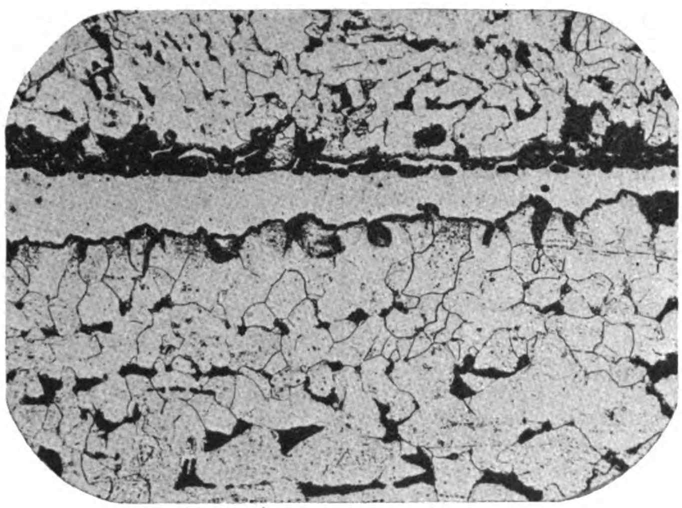


Fig. 683-1.—Magnification, 100 diameters. Etching, nitro-picric acid. Remarks: 1020 steel Hyde welded. Joint horizontal through middle; grains only slightly enlarged.

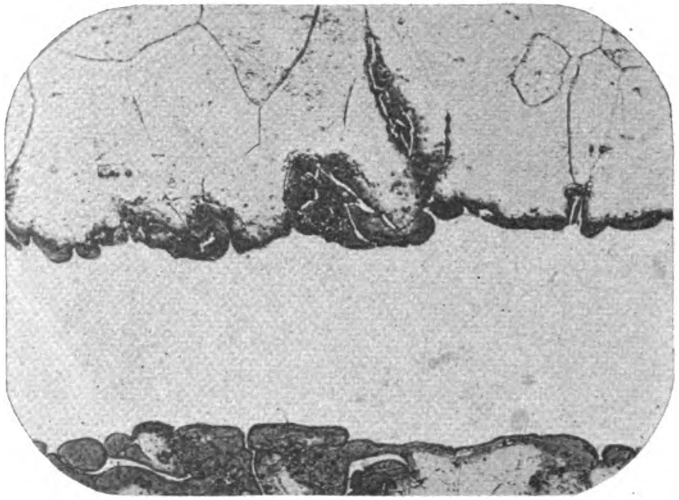


FIG. 683-2.—Magnification, 500 diameters. Etching, nitro-picric acid. Remarks: Same as 683-1 at higher magnification. Copper-light; copper—iron solution—brown (dark in photograph).

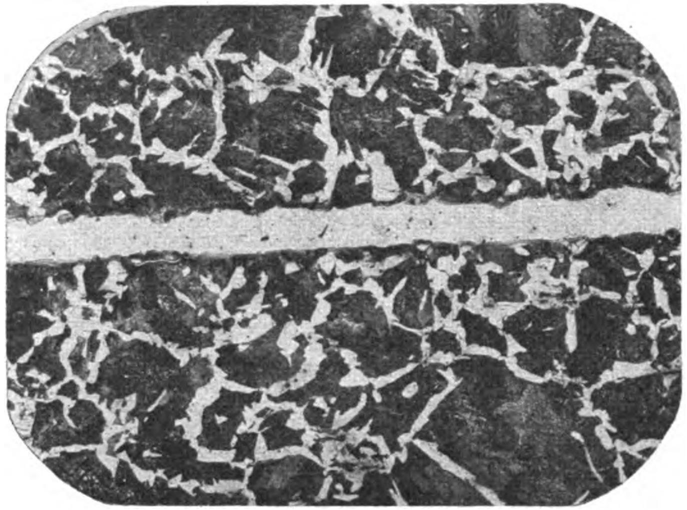


FIG. 683-3.—Magnification, 100 diameters. Etching, nitro-picric acid. Remarks: 1045 steel Hyde welded specimen. Enlarged grains. Joint horizontal through middle.

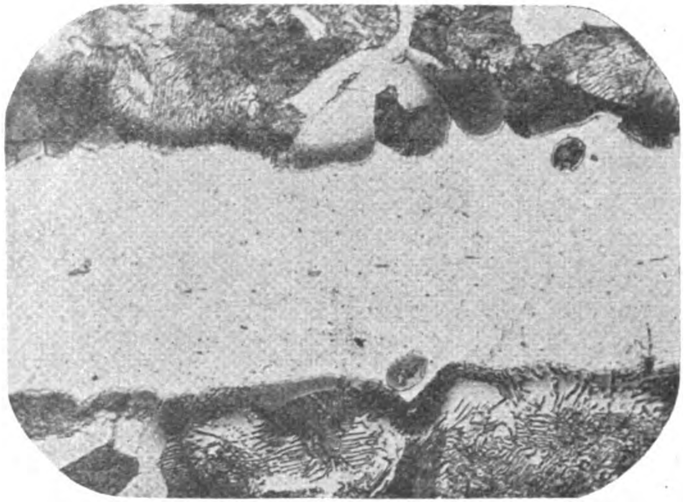


FIG. 683-4.—Magnification, 500 diameters. Etching, nitro-picric acid. Remarks: Same as 683-3 at higher magnification. Copper—center light: copper—iron solution—brown (dark in photograph).

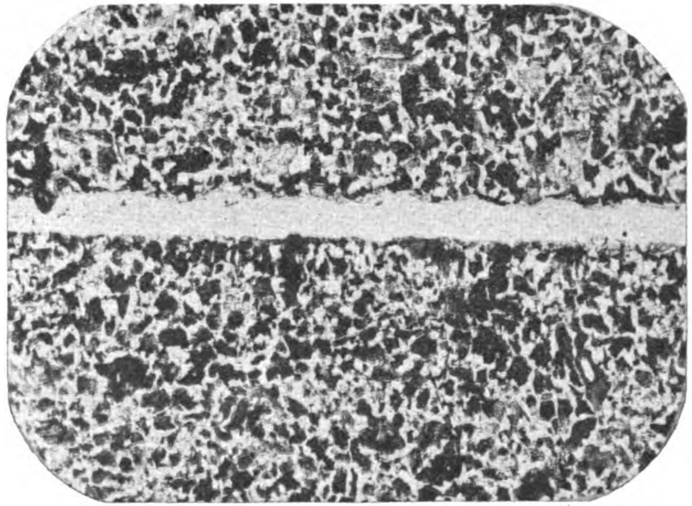


FIG. 683-5.—Magnification, 100 diameters. Etching, nitro-picric acid. Remarks: Same specimen as 683-3 after furnace cooling from 1,500° F. Grains, satisfactorily reduced.

McCOOK FIELD REPORT, SERIAL No. 1919

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV August 15, 1922 No. 365

STATIC TEST OF THE AEROMARINE PG-1 AIRPLANE

(AIRPLANE SECTION S. & A. BRANCH)

▽

Prepared by E. R. Weaver
Engineering Division, Air Service
McCook Field, Dayton, Ohio
April 20, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

STATIC TEST OF THE AEROMARINE PG-1 AIRPLANE.

SUMMARY OF RESULTS.

Airplane: Aeromarine PG-1
Type: Biplane.
Total weight: 3,918 pounds.
Wing cellule weight: 668 pounds.
Wing area: 393 square feet.

Engine: Wright, 350 horsepower.

Description: The PG-1 airplane is a biplane with an armored fuselage. The 8-cylinder Wright engine mounts a 37-mm. cannon. The wings are of wood construction, while the tail surfaces and fuselage are of steel construction. Fabric is used for covering.

Results of test.

Date.	Part tested.	Load required.	Pounds per square foot or factor supported.	Failed at—	Weight.	Failure.
1921. Dec. 6	Horizontal stabilizer.	30 pounds per square foot.	15 pounds per square foot.	20 pounds per square foot.	1.7 pounds per square foot.	Rear spar failed in bending.
Do..	Elevator..........	.....do	20 pounds per square foot.	....	1.26 pounds per square foot.	Elevator and elevator controls were not given the required loading due to early stabilizer failure.
Do..	Elevator control. .	6.............	5.............		....	
Do..	Vertical fin........	25 pounds per square foot.	25 pounds per square foot.	....	1.29 pounds per square foot.	Fin is satisfactory structurally.
Do..	Rudder...........	.....do........	.....do........	....	1.16 pounds per square foot.	Rudder is satisfactory structurally.
Do..	Rudder control....	5.............	2.............	3.............	....	Rudder pedal failed by twisting.
Dec. 7	Ailerons..........	25 pounds per square foot.	25 pounds per square foot.	....	0.918 pound per square foot.	Aileron satisfactory structurally. Failure of bell crank in wing cellule by twisting.
Do..	Aileron control....	5.............	3.............	4.............	....	
	Wing cellule:					
Dec. 14	High incidence.	Factor 7.......	6.............	6.5...........	1.71 pounds per square foot.	Right upper front spar failed at load factor of 6.5.
Dec. 12	Low incidence .	4.5...........	4.5...........	....	....	Wing cellule unsatisfactory structurally.
Dec. 8	Reverse load...	3.............	3.............	....	....	Do.
1922. Jan. 9	Six foot length of leading edge.	14............	15............	16.32.........	....	Leading edge satisfactory structurally.
1921. Dec. 20	Fuselage..........	6.............	6.5...........	7.............	832.5 pounds..	For bending test, fuselage satisfactory structurally.
1922. Mar. 4	Tail skid.........	36-inch drop...	18-inch drop...	24-inch drop...	....	For impact test, rear part of fuselage is structurally weak.
1921. Dec. 23	Chassis:					
	Strut	6.............	5.............	....	71 pounds less wheels.	With recommended changes the landing chassis is structurally satisfactory.
	Axle..........	5.5...........	5.............	....		
	Shock absorber	5.............	4.5...........	5.............		

Weight of 2 wheels=52 pounds.

DISCUSSION.

Due to the fact that the rear stabilizer spar failed at less than the required load, it was impossible to test the elevator controls up to the required load factor. Likewise, the landing chassis shock-absorber fitting failure prohibited the testing to destruction of the axle and struts.

OBJECT.

This static test was conducted for the purpose of determining the structural strength of the Aeromarine PG-1 airplane submitted in accordance with contract No. 354, dated March 15, 1921..

This airplane was designed at McCook Field, Dayton, Ohio, and built by the Aeromarine Corporation of Keyport, N. J., and bore the Air Service No. 64244.

DATE AND PLACE.

The following-named parts were all tested at McCook Field, Dayton, Ohio, on dates mentioned below:

1. Dec. 6, 1921........Elevator and stabilizer.
2. Dec. 6, 1921........Rudder and fin.
3. Dec. 7, 1921........Ailerons.
4. Dec. 8, 1921........Wing cellule (reverse flight).
5. Dec. 12, 1921........Wing cellule (low incidence).
6. Dec. 14, 1921........Wing cellule (high incidence).
7. Dec. 20, 1921........Fuselage.
8. Dec. 23, 1921........Chassis.
9. Jan. 9, 1922........Leading edge test.
10. Mar. 31, 1922........Tail skid test.

WITNESSES.

Lieut. C. N. Monteith...Tests Nos. 1, 2, 3, 4, 5, 6.
Lieut. E. W. Dichman...Tests Nos. 1, 2, 3, 4, 5, 6, 7, 8.
I. M. Laddon...........Tests Nos. 1, 4, 5, 6, 7.
Ray Whitman...........Tests Nos. 1, 2, 4, 5, 6, 7.
W. E. Savage............Tests Nos. 1, 2, 3, 4, 5, 6, 7, 9, 10.
D. B. Weaver............Tests Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9.

SUMMARY.

WING CELLULE.

Static test loading schedules were based on a total weight of 3,918 pounds and a wing weight of 610 pounds.

REVERSE LOADING TEST.

Load factor required, 3.

Inclination of wing chord 14° from horizontal, with trailing edge down. The center of gravity of load was a distance back from the leading edge equal to 25 per cent of wing chord on both upper and lower wings. Load carried to a factor of 3 without failure.

LOW INCIDENCE LOADING.

Load factor required, 4.5.

Inclination of wing chord was 7° 7′ with trailing edge of wing down. The center of gravity of the load was a distance from the leading edge of the wing equal to 46 per cent of the chord. Load carried to a load factor of 4.5, but at load factor of 3.5 the lower wing commenced to tilt backward severely.

HIGH INCIDENCE LOADING.

Load factor required, 7.

The center of gravity of the load was a distance from the leading edge of the wing equal to 31 per cent of the chord. The angle of inclination was 7° 54′, leading edge down. With a load equal to a factor of 5 the compression tube in the upper front spar deflected severely and was braced to continue the test. The right upper front strut fitting failed in bending with a load equal to a factor of 6.5.

Aileron load required, 25 pounds per square foot. Surfaces held satisfactorily.

ELEVATORS AND STABILIZER.

Load required, 30 pounds per square foot.

Load carried to 20 pounds per square foot when rear spar of stabilizer failed in bending.

RUDDER AND FIN.

Load required, 25 pounds per square foot.

Load carried to 27.5 pounds per square foot without failure to surfaces, but controls failed at 15 pounds per square foot.

FUSELAGE.

Load factor required, 6.

Load carried to a factor of 7 when failure occurred.

LANDING GEAR.

Load factor required, 6.

Load carried to a factor of 5 for one minute when the right shock absorber fitting failed. The two five-sixteenths-inch cap screws at the ends of the shock-absorber fitting failed by shearing, while the center three-eighths inch screws pulled through the lower part of the fitting. The struts and axle withstood loading.

GENERAL RECOMMENDATIONS.

WINGS.

Redesign strut fitting.

Laminations in interplane struts to be arranged so that no two splices occur closer than 1 inch apart.

Insert three-sixteenths-inch inside diameter, one-fourth-inch outside diameter, steel spacer tubes where bolts pass through interplane struts.

Redesign upper front spar compression tube to prevent severe deflection.

Redesign aileron push rod and bell crank to withstand a load of 25 pounds per square foot on aileron.

Substitute standard shear bolts and nuts for clevice pins on all cable terminals.

STABILIZER AND ELEVATOR.

Simplify and make more accessible the rear stabilizer spar anchorage.

Redesign stabilizer rear spar to eliminate failure in bending.

RUDDER AND FIN.

Eliminate conical supports for foot pedals and substitute brackets attached to inclined baffle plate.

FUSELAGE.

None.

LANDING GEAR.

Shock absorber and fittings should be redesigned to withstand a load equivalent to a factor of 6, the required load factor for the struts.

GENERAL DESCRIPTION.

The PG-1 airplane is a single-seater armored biplane, with an 8-cylinder 350 horsepower Wright geared engine, on which is mounted a 37-m.m. cannon, which shoots through the propeller hub.

Specified performance, 125 miles per hour at ground.

Climb not important.

Ceiling not important.

Total weight, 3,818 pounds.

Useful load, 810 pounds.

Wing area, 389.30 square feet.

Weight per square foot, 10.12 pounds.

Weight per horsepower, 13.13 pounds.

Aerofoil U. S. A.-15 upper wing.

Aerofoil U. S. A.-27 lower wing.

List of equipment may be seen in section 5 of Specification 1521-A.

Figure 1 is a plan view of the PG-1 airplane.

Figure 2 shows front and side views.

WING CELLULE.

DESCRIPTION.

The wing cellule is of wood construction with box-type spars. There are two spars in the upper wing panel which has a 100-inch chord and one spar in the lower panel which has a 35-inch chord.

The main spar members are spruce, routed so as to make an I beam. Two of these I beams are joined at top and bottom by plywood one-eighth-inch thick, thus forming a box spar.

Aerofoil U. S. A.–15 is used for the upper wing and the lower wing U. S. A.–27 section.

The ribs of these wing panels are made of plywood, 3-ply Spanish cedar with poplar core and spruce cap strips.

Figure 3 is an assembly drawing of the upper wing panel.

Figure 4 is an assembly drawing of the lower wing panel.

Figure 5 shows an interplane strut and typical sections.

PROCEDURE FOR TEST (REVERSED FLIGHT).

The airplane was assembled and set in its normal position (right side up), the wing chord making an angle of 14° to the horizontal.

The center of gravity of the load on the wings was placed at 25 per cent of the wing chord from the leading edge.

The wings were then loaded in accordance with the loading schedule in Figure 6.

RESULTS.

The required load factor for a reverse flight test on wings of an airplane of this type is 3. The wings supported a load factor of 3 without any failure.

Figure 7 is a table of the spar deflections of the lower wing.

Figure 8 is a chart of the deflection curves.

PROCEDURE FOR TEST (LOW INCIDENCE).

The airplane was reset in an inverted position and loaded according to the loading schedule in Figure 9.

The angle of inclination of the wing chord to the horizontal (angle γ) was $7°-7'$, trailing edge down. This was determined from the high-speed angle of incidence α and the angle β between the lift and the resultant air force.

$$\alpha=-1°$$
$$\beta=6°-7'$$
$$\gamma=\beta-\alpha=6°-7'-(-1°)=7°-7'$$

The center of gravity of the load was located at 46 per cent of the wing chord, which corresponds to the position of the center of pressure of the wing at high speed.

The wings on this test were required to support a load factor of 4.5.

RESULTS.

No failures occurred during this test, but the lower wing tilted backward and downward on the strut fittings and deflected badly while supporting a load factor of 3.5. The wing structure supported the required load factor of 4.5.

Figure 10 is a table of spar deflections.

Figure 11 is a chart of the deflection curves.

DISCUSSION.

The tilting of the lower wing was due primarily to the fact that this wing has only one box-type spar and the bearings on the bottom of the interplane struts are insufficient to prevent rotation of the wing panels at these points.

CONCLUSION.

The wing structure supported the required loading.

RECOMMENDATIONS.

Redesign strut fittings at bottom of struts, so as to give more bearing on the wing spar. This will prevent the wing panel from twisting about these points.

PROCEDURE FOR TEST (HIGH INCIDENCE).

The airplane was reset and the wings loaded in acordance with the loading schedule in Figure 12.

The angle of inclination (γ) of the wing chord with the horizontal was $-7°-54'$, leading edge down. This was determined from the angle where the center of pressure is farthest forward, α, and β, the angle between the lift and the resultant air force.

$$\alpha=15°$$
$$\beta=\text{L/D} \cot^{-1} 8.03=7°-6'$$
$$\gamma=\beta-\alpha=7°-6'-(15°)=-7°-54'$$

The location of the center of gravity of the load was 31.125 inches from the leading edge, which corresponds to the location of the center of pressure on the wing at $\alpha=+15°$.

RESULTS.

Figure 13 is a table of spar deflections.

Figure 14 is a chart of deflection curves.

Figures 32 and 33 are photographs of the right upper front spar fitting and spar failures.

DISCUSSION.

The load factor required is 7. At a load factor of 5 the compression tube in the center section of the upper front spar deflected severely and had to be braced before the test could be continued.

The right upper front strut fitting failed in bending while the structure was supporting a load factor of 6.5.

CONCLUSION.

The upper front spar fittings are too weak to support the required load. The front spar compression tube in the center section should be heavier.

From the examination and tests of the wing spars made by the Material Section, the following information was obtained:

Right upper front (double) wing beam, front and rear members, slightly lower in specific gravity than that for average grade of spruce, good strength properties.

Right upper rear (double) wing beam and front and rear members gave slightly lower specific gravity and strength properties than those for average grade of spruce.

Right lower (double) wing beam and front and rear members compared favorably in strength properties with those for average grade of spruce.

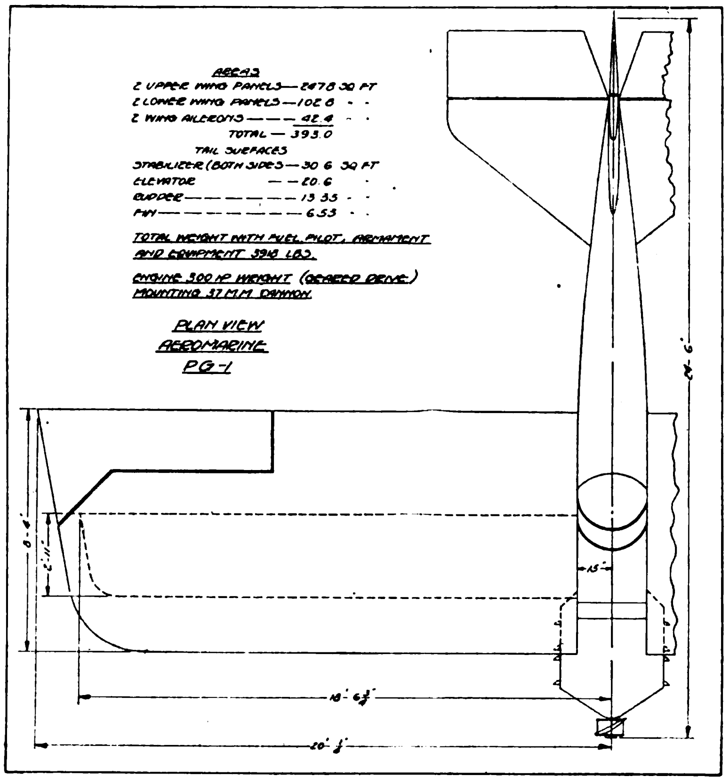


Fig. 1.—Plan view of airplane.

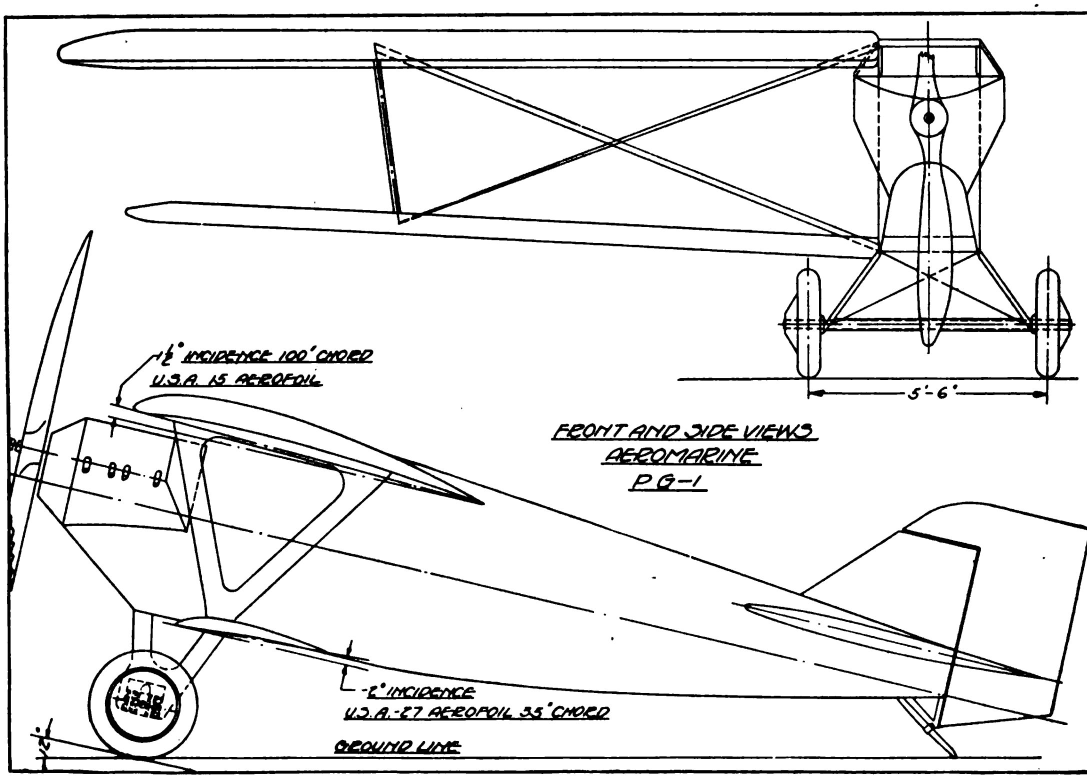


Fig. 2.—Front and side views of airplane.

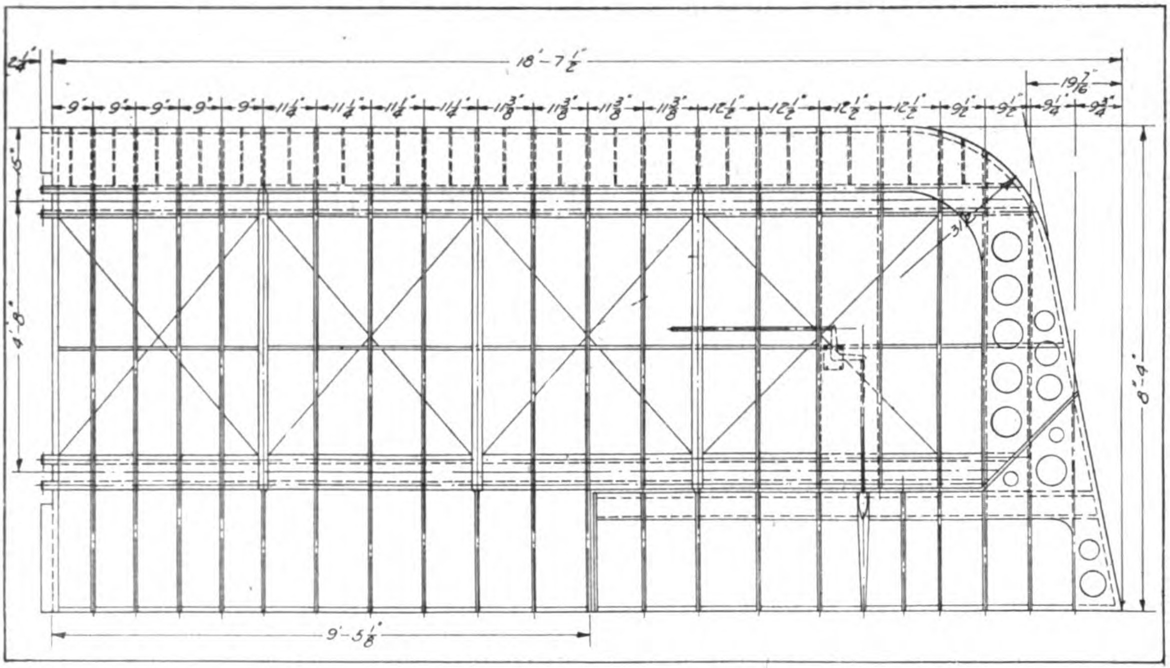


Fig. 3.—Assembly drawing (upper wing).

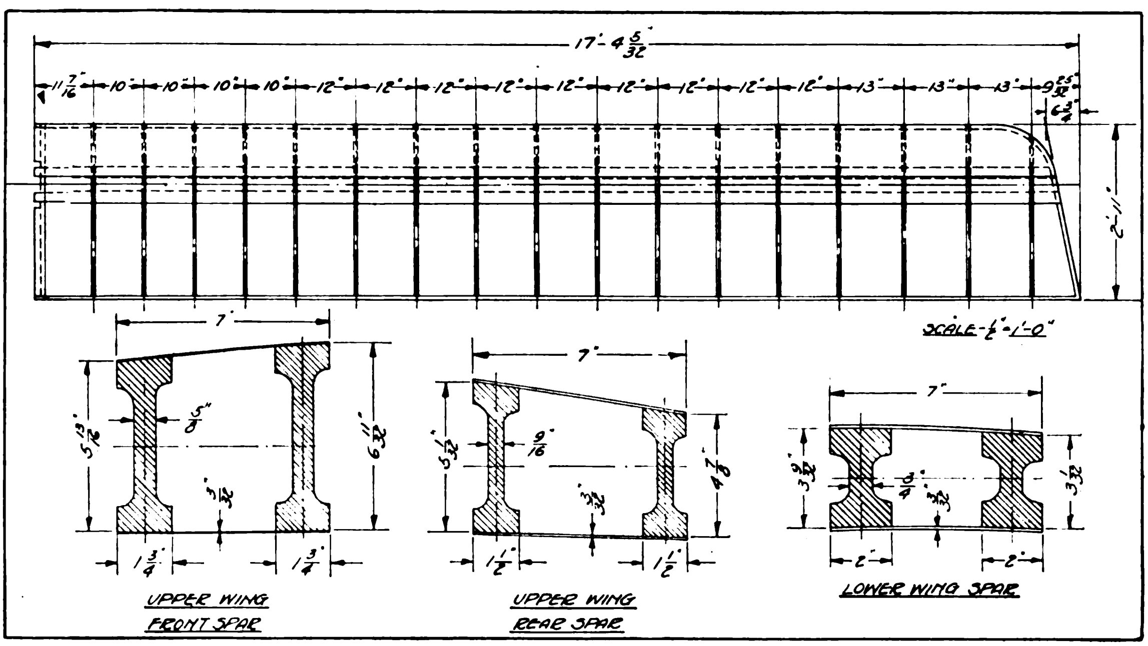


Fig. 4.—Assembly drawing (lower wing).

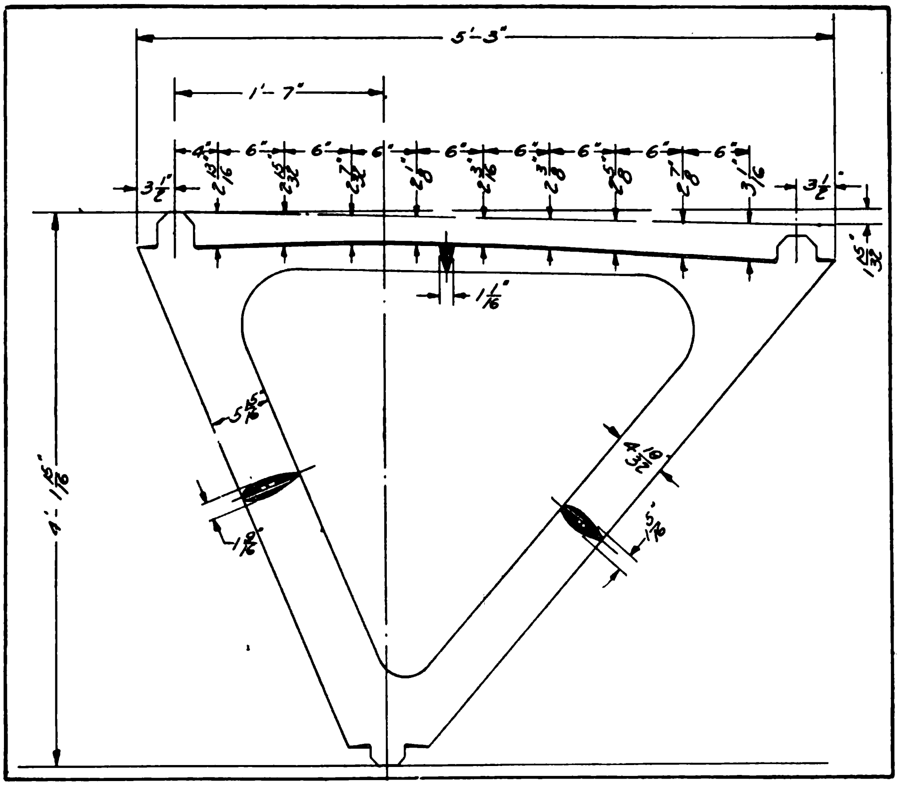
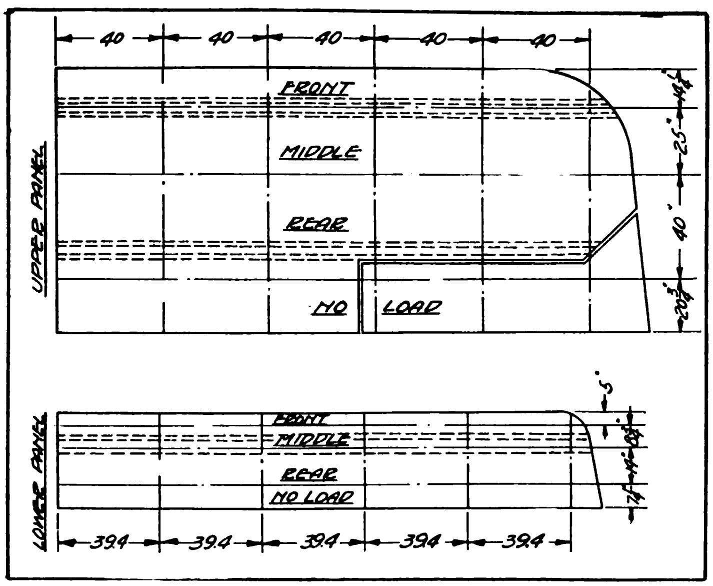


Fig. 5.—Drawing of V-strut and sections.

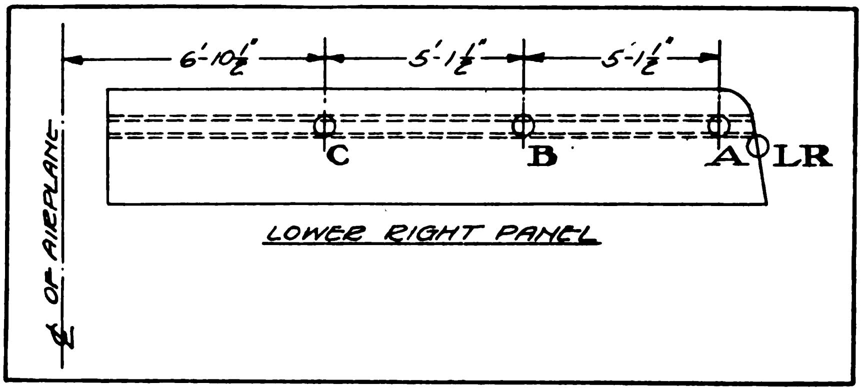


REVERSE LOADING.

LOADING SCHEDULE FOR UPPER AND LOWER WINGS.

Load factor.	Upper wing.			Total load.	Lower wing.			Total load.
	Front.	Middle.	Rear.		Front.	Middle.	Rear.	
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
2	221	111	111	4,430	79	39	39	1,570
2.5	282	142	141	5,660	100	50	50	2,000
3	343	173	171	6,870	121	61	61	2,430

Fig. 6.—Loading schedule—reversed flight.



REVERSE LOADING DEFLECTION OF LOWER WING SPAR.

Load factor.	Deflections in inches at—						Retreat—			
	A	B	C	D	E	F	LR	UR	LL	UL
2	1.8	1.3	1.1	1.2	1.5	2.0	+1.3	−.1	+ .9	−.3
2.5	2.3	1.1	1.5	1.7	2.1	2.9	+1.8	−.3	+1.2	−.4
3	2.8	2.1	1.9	2.2	2.7	3.6	+2.0	−.6	+1.7	−.3

FIG. 7.—Table of spar deflections

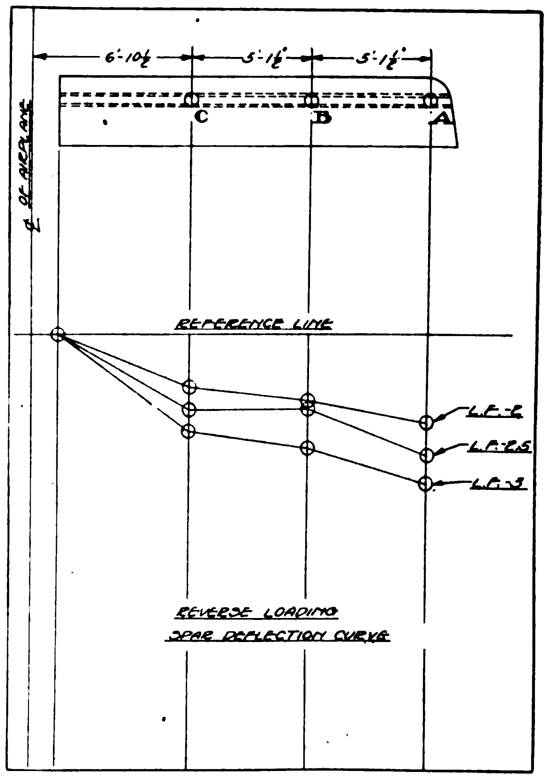
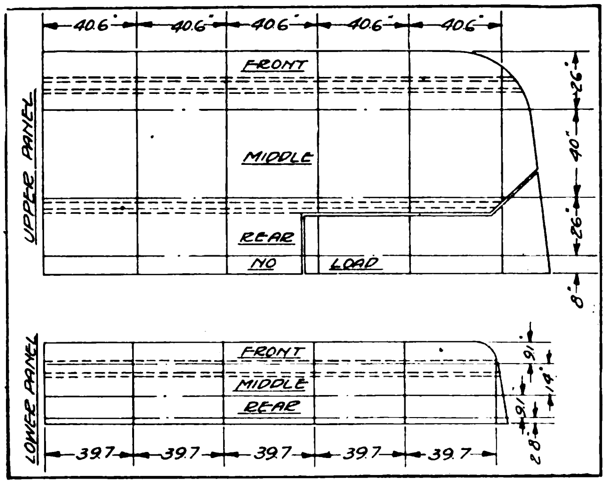


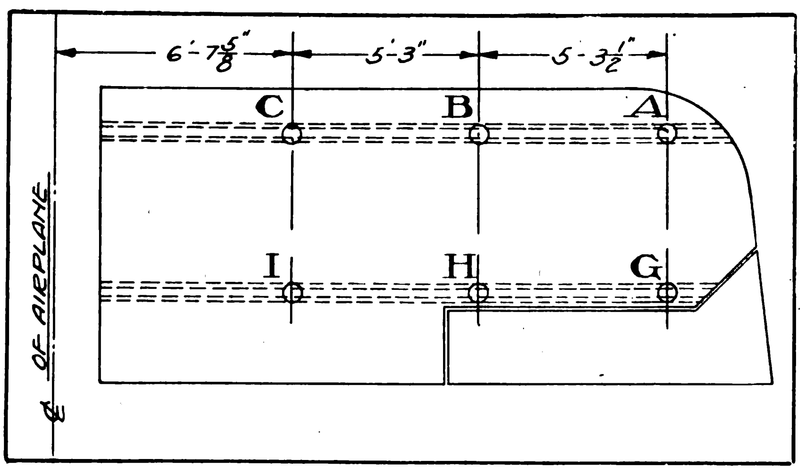
FIG. 8.—Chart showing deflection curves,



LOW INCIDENCE—LOADING SCHEDULE FOR UPPER AND LOWER WINGS.

Load factor.	Upper wing.			Total load.	Lower wing.			Total load.
	Front.	Middle.	Rear.		Front.	Middle.	Rear.	
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
2	142	284	142	5,680	91	181	91	3,630
2.5	167	335	167	6,690	107	213	107	4,270
3	192	386	192	7,700	123	245	123	4,910
3.5	217	437	217	9,710	139	277	139	5,480

FIG. 9.—Loading schedule—low incidence.



LOW INCIDENCE DEFLECTIONS OF SPARS OF UPPER WING.

Load factor.	Deflections in inches measured at—												Retreat.			
	A	B	C	D	E	F	G	H	I	J	K	L	UL	LL	UR	LR
3	2.1	1.3	0.9	0.9	1.2	1.7	2.9	2.1	1.6	1.7	2.1	3.0	+0.4	+2.1	+0.2	+1.8
3.5	1.7	1.2	.9	1.1	1.5	2.4	3.2	2.4	1.9	2.3	3.0	4.1	.7	2.6	.3	1.9
4	1.8	1.3	1.1	1.4	1.9	2.9	3.6	2.7	2.2	2.7	3.6	5.0	1.0	3.3	.4	2.5
4.5	2.1	1.6	1.4	1.6	2.0	3.0	4.1	3.1	2.8	3.2	4.0	5.8	1.1	3.9	−.2	3.0

FIG. 10.—Table of spar deflections.

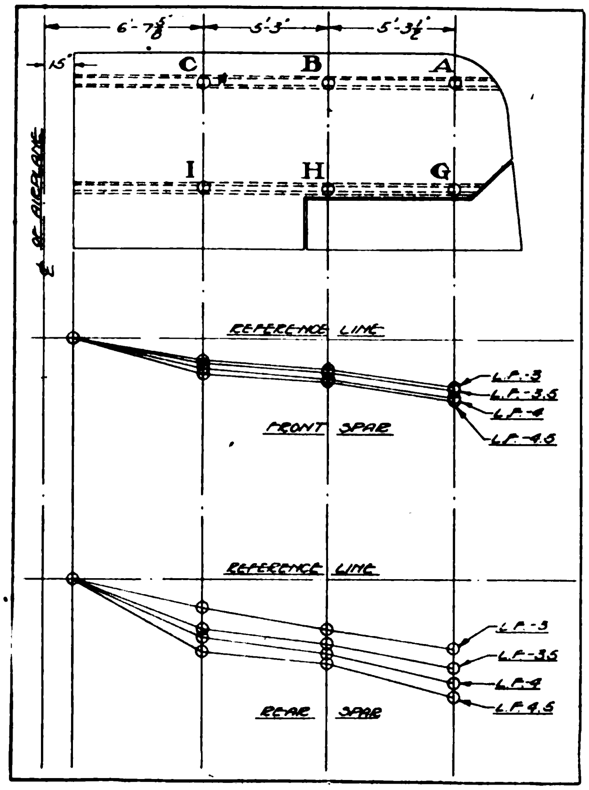
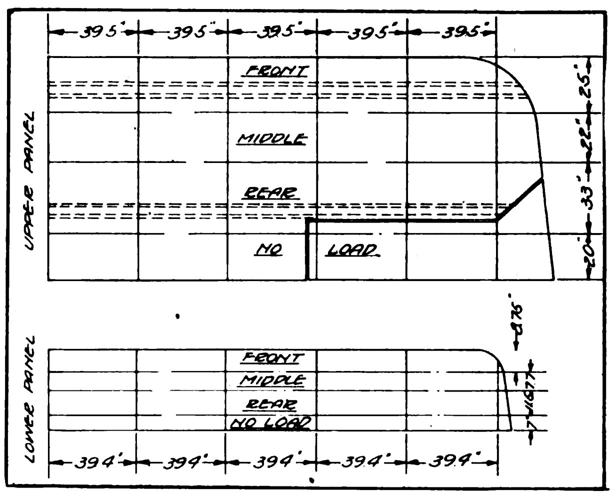


FIG. 11.—Chart showing deflection curves.



HIGH INCIDENCE LOADING SCHEDULE FOR UPPER AND LOWER WINGS.

Load factor.	Upper wing.			Total load.	Lower wing.			Total load.
	Front.	Middle.	Rear.		Front.	Middle.	Rear.	
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
3	326	163	163	6,520	140	70	70	2,800
4	442	221	221	8,840	189	95	85	3,790
5	558	279	279	11,160	238	120	120	4,780
5.5	615	308	308	12,310	262	133	133	5,280
6	672	337	337	13,460	286	146	146	5,780
6.5	729	366	366	14,610	310	159	159	6,280
7	786	395	395	15,760	334	172	172	6,780

FIG. 12.—Loading schedule—high incidence.

Strength properties of double wing beams from the PG-1 airplane.

Location of double beam.	Member of double wing beam.	Moisture content, per cent.	Specific gravity.	Modulus.		Fiber stress at elastic limit, pounds per square inch.	Compression parallel to grain, pounds per square inch.	Span in.
				Rupture, pounds per square inch.	Elasticity, 1,000 pounds per square inch.			
Right upper front.	Front..	7.80	0.375	[1] 11,280	1,560	[1] 8,065	6,985	36
	Rear...	7.84	.396	[1] 11,595	1,661	[1] 7,720	7,680	36
Right upper rear.	Intact..	......	......	[2] 7,250	1,700	4,655	......	102
	Front..	6.81	.400	[3] 7,090	1,800	6,180	6,950	102
	Rear...	7.44	.393	[4] 7,470	1,510	4,150	6,460	84
Right lower.	Intact..	......	......	9,170	1,782	6,570	......	60
	Front..	8.12	.431	8,460	1,965	5,970	7,500	60
	Rear...	8.58	.442	9,610	2,062	4,985	7,350	60

[1] The higher strength properties are due to the smaller test specimens used.
[2] Rear member brash.
[3] Horizontal shear failure.
[4] Spiral grain 1 : 14 and brash.

RECOMMENDATIONS.

More care should be exercised in the selection of wing beam material. The spar fittings and the compression tube with center section should be redesigned to support a load factor of 7.

AILERON.

DESCRIPTION.

The aileron is of wood construction with one main box spar. This spar is made of two spruce members routed so as to form a channel and joined together by three thirty-seconds 3-ply plywood.

The ribs are constructed with plywood webs and spruce cap strips.

Fabric is used for covering.

Figure 15 is a drawing of the aileron structure.

This aileron is of the balanced type, total area 21.21 square feet, area of balanced part 2.26 square feet.

PROCEDURE.

The aileron was loaded according to the loading schedule in Figure 16. The center of gravity of the load was located at five-twelfths of the chord from the hinge center, the load at the trailing edge being one-third the load at the hinge. A spring balance was connected to the control stick which registered the pull in the cables.

RESULTS.

First test.—At a load of 15 pounds per square foot the control stick deflected badly. The corresponding pull on the stick was 90 pounds. At a load of 20 pounds per square foot the ball joint on the end of the link connecting the control stick with the remainder of the control mechanism failed. Considerable crackling of the wing structure was noticed while the aileron was being tested.

Second test.—The aileron was loaded the second time and at a load of 20 pounds per square foot the aileron sagged badly. At a load of 22.5 pounds per square foot the bell crank, which is mounted in the wing structure, failed by twisting. The aileron structure showed no signs of failure.

Figure 17 is a table of the results of both aileron tests.

Figure 34 is a photograph of the ball joint failure.

Figure 35 is a photograph of the bell crank failure.

DISCUSSION.

While no weakness was manifest in the aileron structure during the test, the aileron controls failed before the required load was applied to the surface of the aileron, the required load being 25 pounds per square foot.

CONCLUSION.

The aileron structure is satisfactory structurally, but the controls and linkages thereof are weak.

RECOMMENDATIONS.

Redesign the aileron control system and the mounting of the bell crank in the wing structure so that the control system will stand a load of 25 pounds per square foot without failure.

ELEVATOR AND STABILIZER.

DESCRIPTION.

The elevator and stabilizer are of steel construction. The elevator is built up on a tubular steel spar and has formed sheet steel ribs which are welded together at the seams and riveted to the spar fittings.

The stabilizer main spar is built up of formed sheet steel members welded at the seams. The ribs are made in a similar way. The leading edge is a piece of steel tubing, to which the ribs are joined at their forward ends.

Area of elevators, 20.6 sq. ft., weight=26 lbs.; lbs. per sq. ft., 1.26 lbs.

Area of stabilizers, 30.6 sq. ft., weight=36 lbs.; lbs. per sq. ft., 1.17 lbs.

Figure 18 is a drawing of the elevator structure.

Figure 19 is a drawing of the stabilizer structure.

Figure 20 shows typical sections.

PROCEDURE.

The elevator and stabilizer were mounted on the fuselage and loaded according to the loading schedule in Figure 21. The required load for the elevator and stabilizer was 30 lbs. per sq. ft.

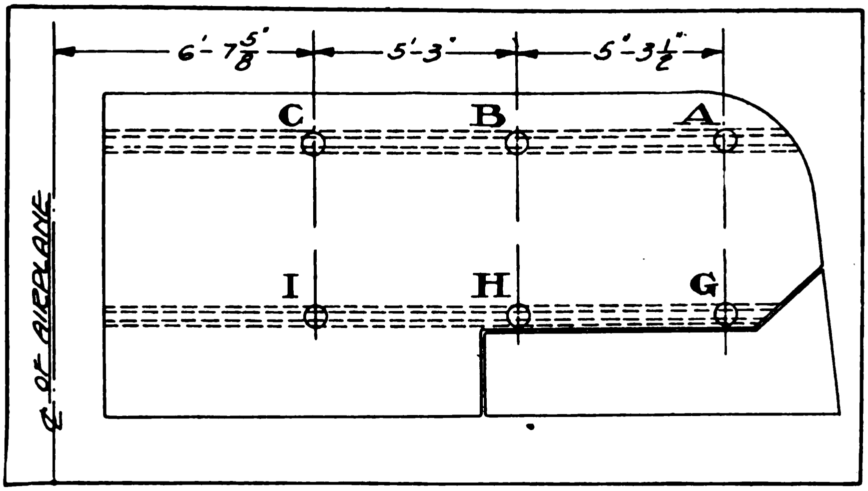
The surfaces were loaded in the ratio of 0.758 on the elevator to 1.137 on the stabilizer.

The center of gravity of the load on the elevator was located at five-twelfths of the chord from the center line of the hinge, the load at the trailing edge being one-third the load at the hinge.

RESULTS.

The first failure was the buckling of the rear spar of the stabilizer at a load of 20 pounds per square foot. The right side collapsed. The test was continued on the left side of stabilizer and at 27.5 pounds per square foot failure occurred.

The elevator and the controls are satisfactory structurally.



HIGH INCIDENCE DEFLECTIONS OF SPARS OF UPPER WING.

Load factor.	Deflections in inches measured at—												Retreat.			
	A	B	C	D	E	F	G	H	I	J	K	L	UL	LL	UR	LR
3	1.9	1.4	1.2	1.2	1.5	2.2	1.2	0.9	0.9	0.9	0.9	1.3	+.2	−.4	−0.5	+.2
4	1.9	1.9	1.7	1.8	3.6	3.1	1.6	1.2	1.2	1.2	1.3	1.6	.3	−.6	−0.3	+1.1
5	2.9	2.3	2.1	2.4	4.5	4.5	1.7	1.3	1.4	1.5	1.7	2.4	.4	−.8	−0.6	−2.1
5.5	3.4	2.6	2.4	2.8	4.5	4.9	1.9	1.5	1.6	1.7	2.0	2.6	.5	−1.0	−0.7	−2.5
6	3.8	3.1	2.8	3.1	4.5	5.6	2.2	1.7	1.8	1.9	2.0	2.8	.3	−1.2	−0.7	−3.0
6.5	Failure.															
7	Required load factor.															

NOTE.—At a load factor of 5 the upper spar center section compression tube deflected $\frac{1}{16}$", at A. L. F. of 6 the tube deflected $\frac{1}{8}$" and had to be reinforced with wood members to prevent failure.

FIG. 13.—Table of spar deflections.

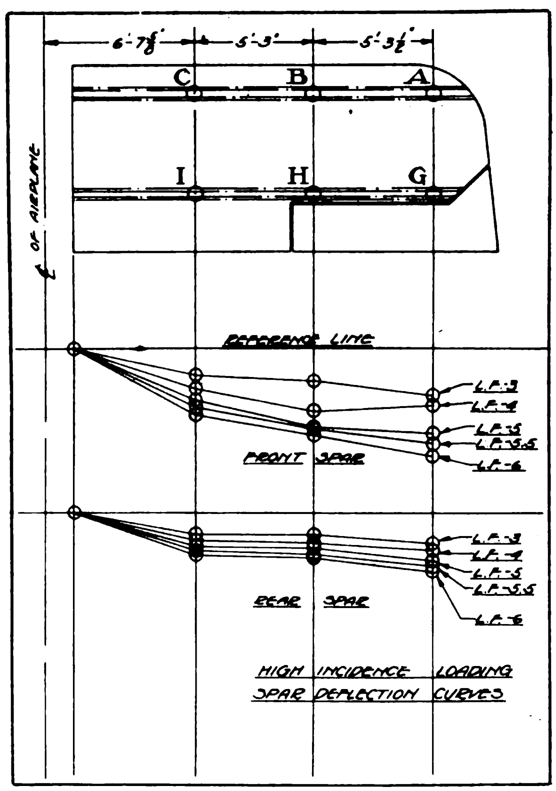


FIG. 14.—Chart showing deflection curves.

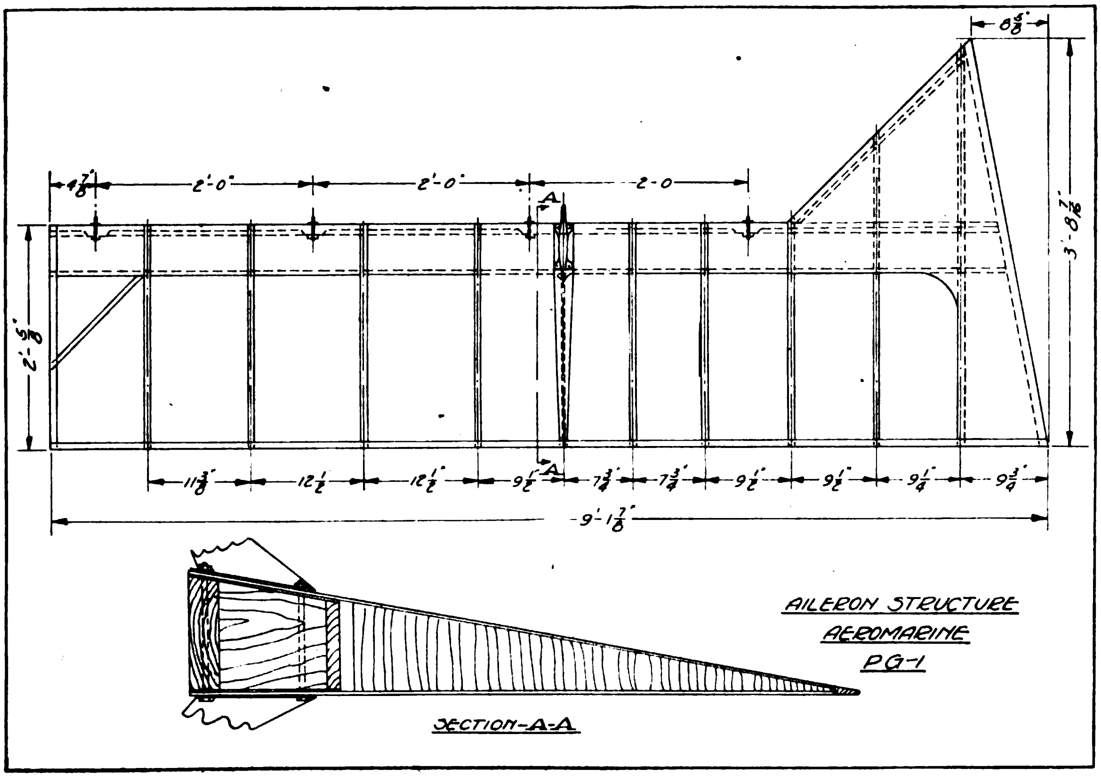
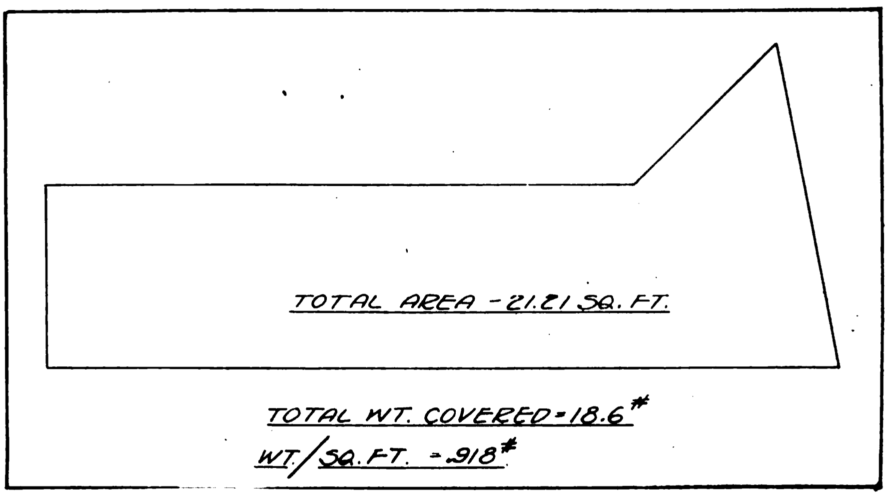


FIG. 15.—Aileron structure.



AILERON LOADING SCHEDULE.

Lbs./ sq. ft.	Load on aileron proper.	Load on balanced part.	Total load on surface.	Lbs./ sq. ft.	Load on aileron proper.	Load on balanced part.	Total load on surface.
	Pounds.	*Pounds.*	*Pounds.*		*Pounds.*	*Pounds.*	*Pounds.*
5	90	16	106	20	360	64	424
10	180	32	212	22.5	405	72	477
15	270	48	318	25	450	80	530

FIG. 16.—Aileron loading schedule.

Results of aileron tests.

FIRST TEST.

Pounds per square foot.	Pull on stick.	Remarks.
	Pounds.	
5	25	
10	55	
15	90	Control stick deflecting badly.
20	....	Failure of ball joint on link connecting control stick with crank on vertical tube.
22.5	....	
25	....	Required loading.

SECOND TEST.

5	([1])	
10	([1])	
15	([1])	
20	([1])	Aileron sagging badly.
22.5	([1])	Failure of bell crank mounted in wing cell. This failure was due to eccentric loading.
25	([1])	

[1] Failure of ball joint eliminated control stick; pull could not be registered.

FIG. 17.—Table of aileron results.

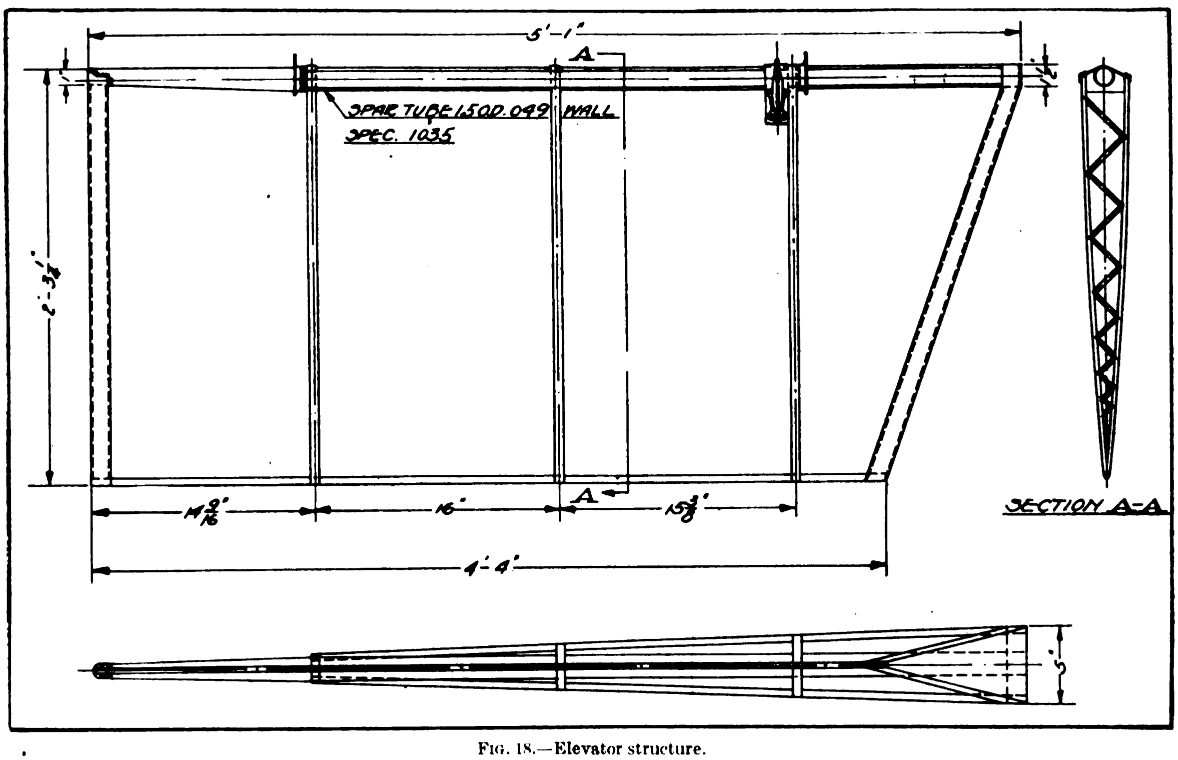


FIG. 18.—Elevator structure.

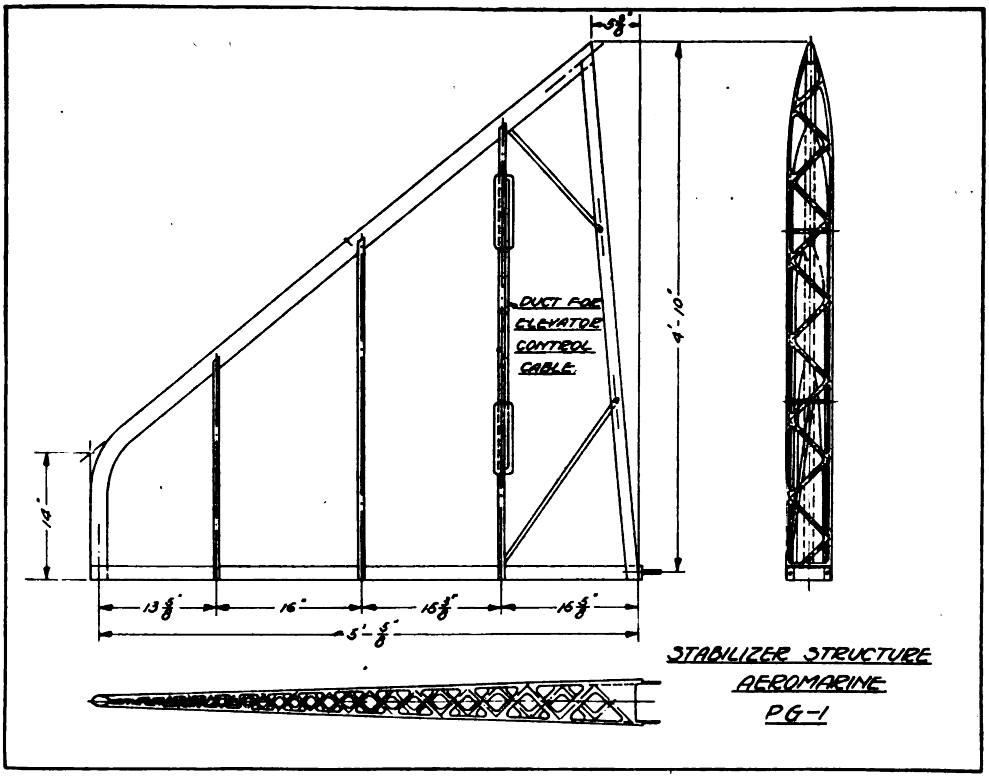


FIG. 19.—Stabilizer structure.

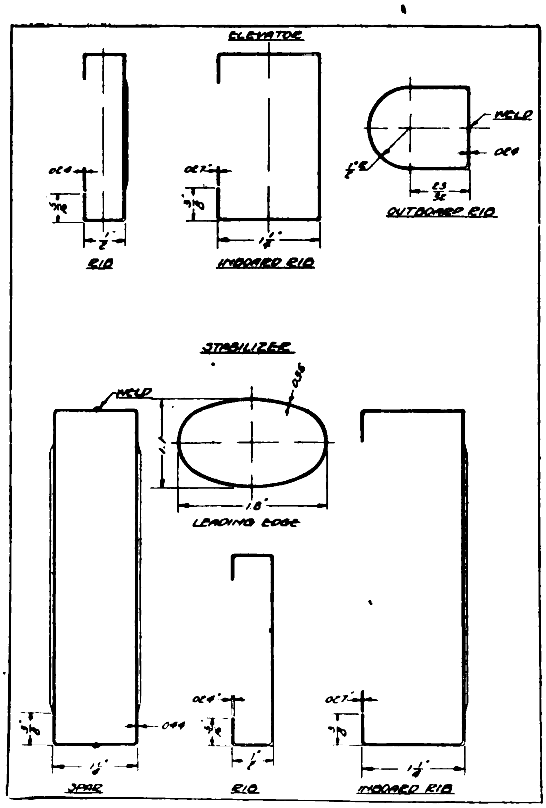
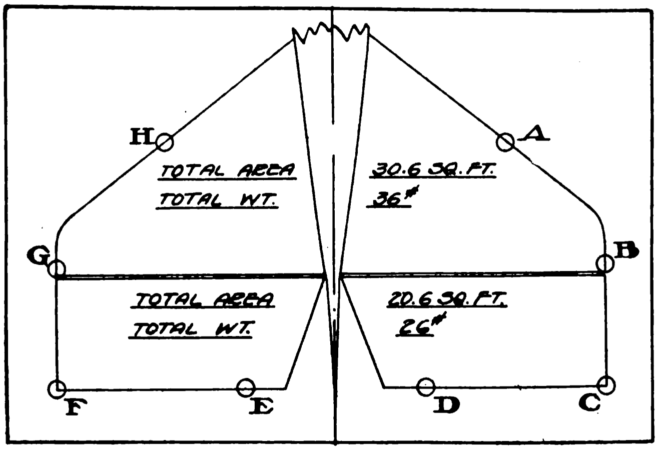


FIG. 20.—Typical section of elevator and stabilizer.



LOADING SCHEDULE AND RESULTS OF ELEVATOR AND STABILIZER TEST.

Pounds per square foot.	Load on elev.	Load on stab.	Total load.	Pull on stick.	Deflections in inches at—							
					A	B	C	D	E	F	G	H
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*								
5	82	174	256	30	0.3	0.5	1.7	1.3	1.2	1.4	0.1	0.2
10	164	348	512	60	.5	3.6	3.0	2.5	1.7	3.3	.5	.5
15	246	522	768	95	.9	5.6	4.8	3.8	4.4	5.4	.9	.9
20	328	696	1,024	....	First failure.				8.4	12.9	5.5	4.2
22.5	369	783	1,152	....	Deflections discontinued.							
25	410	810	1,280	....	....	....	....	....	....	....	....	....
27.5	451	957	1,408	....	Second failure.				....	....	....	....
30	492	1,044	1,436	....	....	....	....	....	....	....	....	....

First failure at loading of 20 pounds per square foot right rear stabilizer spar buckled between first and second rib from fuselage.

Second failure at loading of 27.5 pounds per square foot left rear stabilizer spar.

FIG. 21.—Loading schedule and results of test.

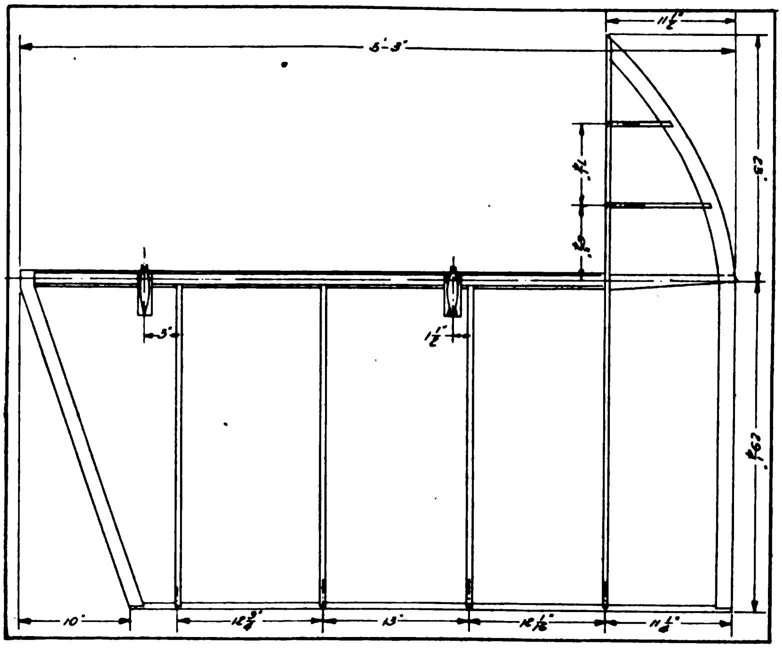


FIG. 22.—Rudder structure.

Figure 21 gives the deflections and results of the test.

Figure 36 is a photograph of the failure of the right side of the stabilizer spar.

Figure 37 is a photograph of both right and left spar failures.

DISCUSSION.

By the use of two external braces the stabilizer structure could be made to support the required load, but if it is desired to do away with all external brace members on the tail surfaces, the rear stabilizer spar must be made heavier.

CONCLUSION.

The rear spar of the stabilizer is weak.

RECOMMENDATIONS.

Redesign the rear spar of stabilizer to support the required loading of 30 pounds per square foot on the horizontal tail surfaces, or add external brace members.

RUDDER AND FIN.

DESCRIPTION.

The rudder and fin are both of steel construction.

The rudder is built on a steel tubular spar with ribs of formed sheet steel welded at the joints and riveted at the fittings. The trailing edge is an eliptical tube bent to shape and welded to the ribs, the ribs being welded to main spar. The rudder is of the balanced type and is covered with fabric.

The fin is built of formed steel members and tubes welded at the joints. The main frame and leading edge is formed sheet steel, while the brace members are steel tubes. The rudder hinges are brazed to the frame.

Fabric is used for covering.

The following is a table of areas:

	Area.	Weight.	Weight per square foot
	Square feet.	*Pounds.*	*Pounds.*
Rudder	13.33	15.5	1.16
Balanced part	1.00		
Fin	6.53	8.43	1.29

Figure 22 is a drawing of rudder structure.

Figure 23 is a drawing of fin structure.

Figure 24 shows typical sections.

PROCEDURE.

The rudder and fin were assembled on the fuselage and the fuselage turned on its side and properly supported. A spring balance was attached to the rudder pedal to register the pull in the controls.

The center of gravity of the load on the rudder was located at five-twelfths of the chord from the hinge center, the load at the trailing edge being one-third the load at the hinge center.

The surfaces were loaded according to the loading schedule in Figure 25.

The required load was 25 pounds per square foot.

RESULTS.

The results and deflections are tabulated in Figure 25. The rudder and fin are satisfactory structurally, having supported a load of 27.5 pounds per square foot. The rudder pedal started to twist at a load of 15 pounds per square foot.

CONCLUSION.

The rudder and fin are satisfactory structurally, but the rudder pedals showed too much torsional deflection.

RECOMMENDATIONS.

The rudder pedals should be redesigned to stand a load of 25 pounds per square foot on the rudder.

FUSELAGE.

DESCRIPTION.

The entire fuselage is of steel construction, the forward part being armored with three-sixteenths armor plate. The rear portion of the fuselage is of conventional design with steel tube longerons and steel tube brace members.

Figure 26 is a drawing of the fuselage showing plan and side views.

PROCEDURE.

The fuselage was supported on a jig and loaded as per loading schedule, figure 27.

Due to the fact that the forward portion of the fuselage structure is composed of armor plate, the only possible chance of failure was to the rear of the armored portion. The load on the armored part acted merely as a counterbalance for the tail load.

RESULTS.

The deflections and results are shown in Figure 29. The required load factor was 6. The structure supported a load factor of 6.5 and then failed in first bay to rear of the armor plate. The lower longerons failed in compression.

DISCUSSION.

The first failure was the left lower longeron, which failed when the fabric was cut. The tube was drawn back to place by blocks and clamps and a load factor of 7 was imposed. The fabric on the right side was then cut and failure of right longeron followed.

Figure 38 is a photograph of lower longeron failures.

CONCLUSION.

The fuselage is satisfactory structurally.

LANDING CHASSIS.

DESCRIPTION.

The landing chassis is a two strut type chassis with wood struts and sheet steel fittings at the bottom to take the shock absorber. There is a tubular steel axle and horizontal brace members. Double flexible diagonal brace wires are used.

Figure 29 is a drawing of the chassis.

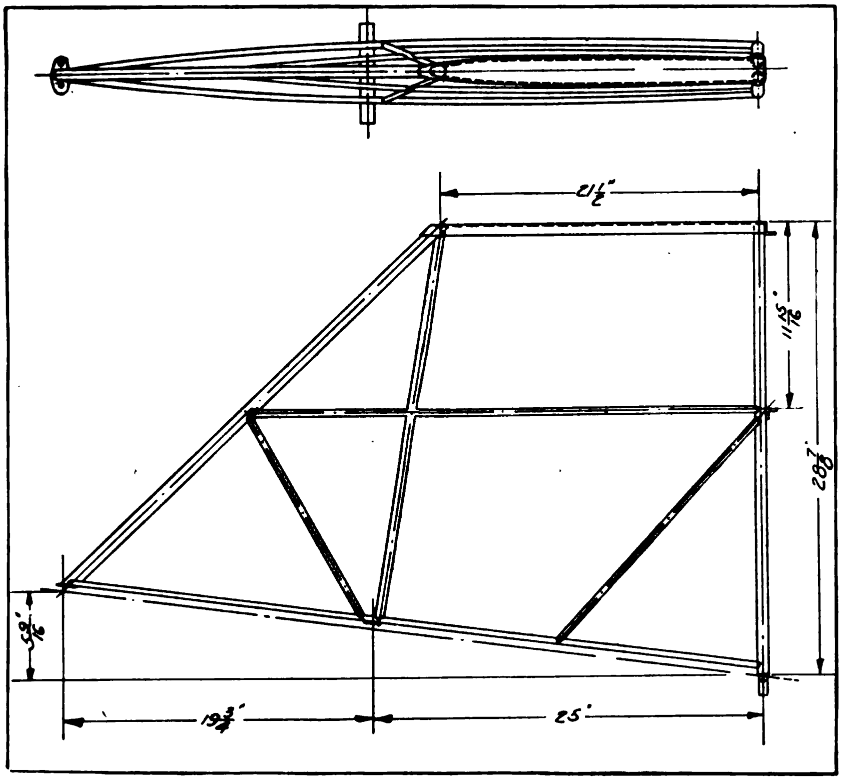


FIG. 23.—Fin structure.

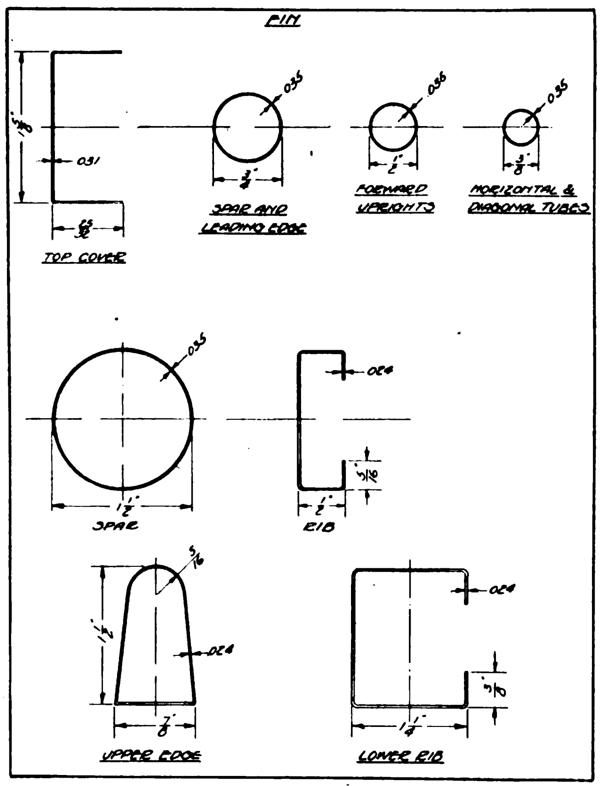
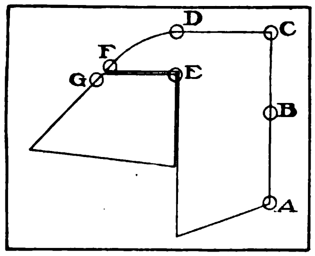


FIG. 24.—Typical sections of fin and rudder.



Area of rudder, 13.33 square feet. Weight = 15.5 pounds.
Area of fin, 6.53 square feet. Weight = 8.43 pounds.

LOADING SCHEDULE AND RESULTS OF RUDDER AND FIN TEST.

Pounds per square foot.	Load on bal. part.	Load on rudder proper.	Load on fin.	Total load on surfaces.	Pull on stick.	Deflections in inches at—						
						A	B	C	D	E	F	G
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*							
5	6	52	40	96	55	.3	0	0	.4	.1	1.3	.1
10	12	104	82	198	95	1.0	0	0	.5	.3	.9	.2
15	18	156	120	294	155	1.5	.7	1.0	.9	.5	.8	.2
20	24	208	164	396	230	1.4	.9	1.4	1.2	.8	1.1	.4
22.5	27	234	185	446	285	1.6	1.1	1.8	1.5	.9	1.1	.4
25	30	260	206	496	305	2.2	1.8	2.6	1.7	1.0	.8	.5
27.5	33	286	227	348		Held required loading.						

Rudder pedal started twisting when average loading was 15 pounds per square foot. At a loading of 27.5 pounds per square foot the deflection of rudder pedal was ½ inch.

FIG. 25.—Loading schedule and results for rudder and fin.

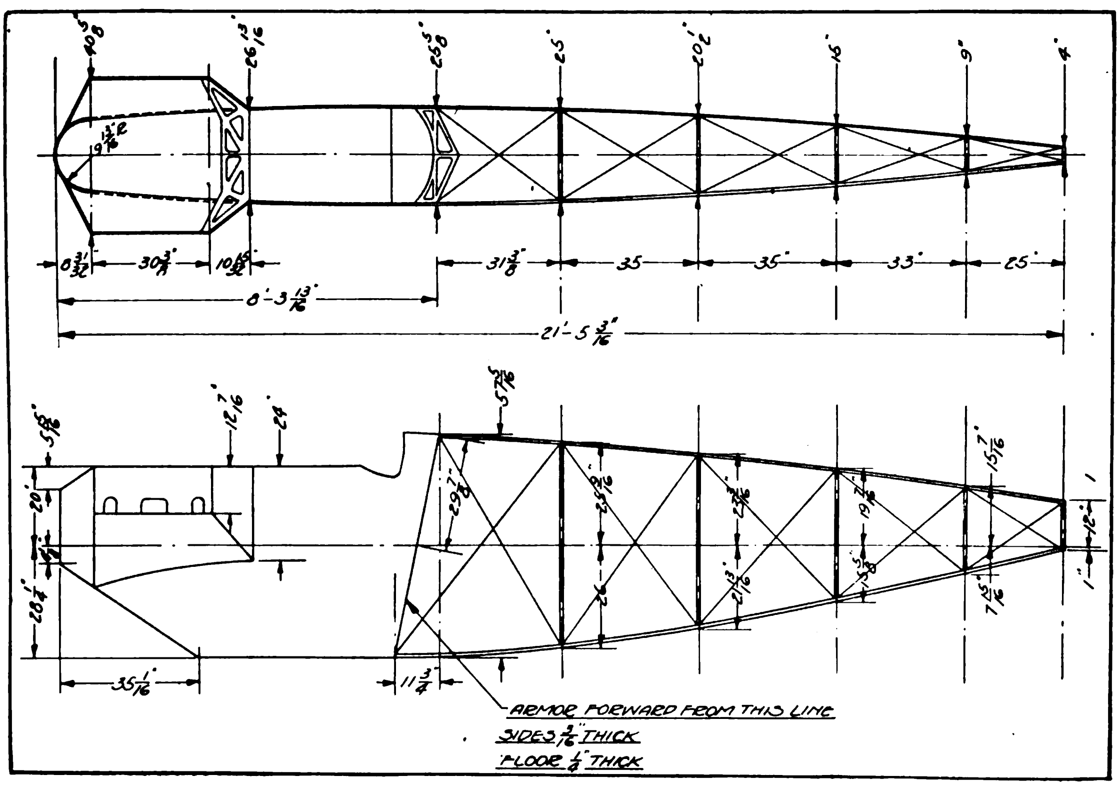
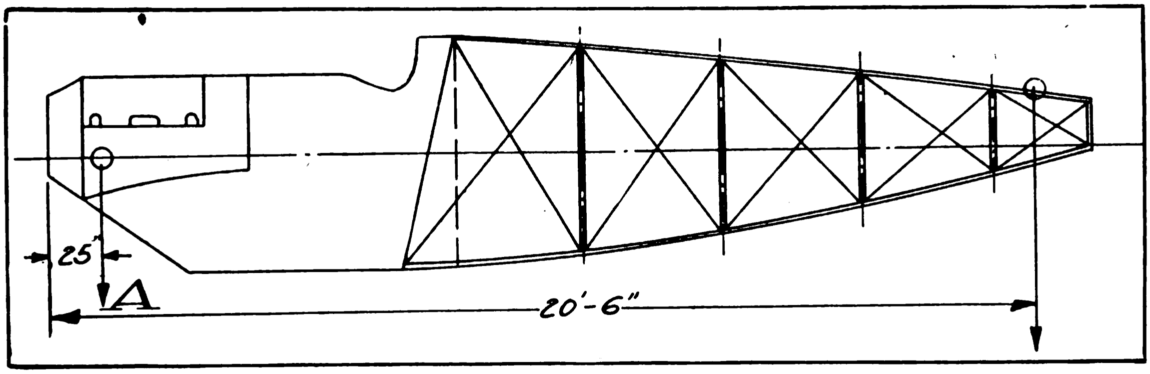


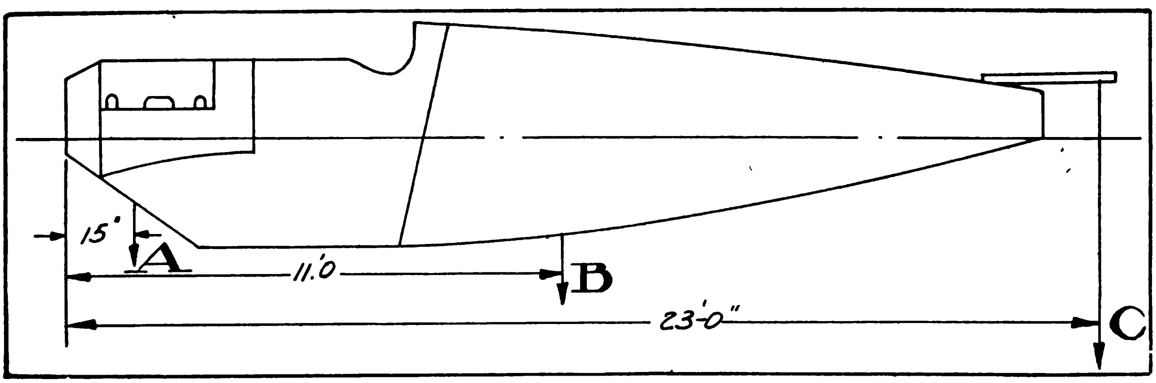
FIG. 26.—Plan and side view of fuselage.



FUSELAGE LOADING SCHEDULE.

Load factor.	Engine load.	Tail load.	Total load.	Load factor.	Engine load.	Tail load.	Total load.
	Pounds.	*Pounds.*	*Pounds.*		*Pounds.*	*Pounds.*	*Pounds.*
2	2,120	733	2,853	5.5	5,830	2,105	7,935
3	3,180	1,125	4,305	6	6,360	2,301	8,661
4	4,240	1,517	5,757	6.5	6,890	2,497	9,387
5	5,300	1,909	7,209	7	7,420	2,693	10,113

FIG. 27.—Loading schedule for fuselage.



DEFLECTIONS AND RESULTS OF FUSELAGE TEST.

Load factor.	Deflections at— A	B	C	Remarks.
2	0	.2	.7	
3	0	.3	1.0	
4	−.1	.3	1.1	
5	−.1	.4	1.6	
5.5	−.1	.4	1.8	
6	−.2	.5	2.0	
6.5	....	....	....	Failure of left lower longeron after fabric was cut, this longeron was
7	....	....	....	reinforced and right lower longeron failed a factor of 7.

FIG. 28.—Deflections and results of fuselage test.

PROCEDURE.

The landing chassis was mounted in the test jig and loaded per loading schedule in Figure 30.

The chassis was mounted in such a way that the center of gravity of the load came vertically over the center of the axle. The shock absorber elastic was not wound evenly on both sides and had to be removed at a load factor of 3, and replaced by a steel cable.

RESULTS.

The right shock absorber fitting failed at a load factor of 5. The two five-sixteenths bolts sheared off while the center three-eighths inch bolt on the lower side pulled entirely through the fitting.

Figure 39 is a photograph of the failure.

CONCLUSION.

The required load factor for the struts is 6. The struts and axle are strong enough, but the shock absorber fittings are weak.

RECOMMENDATIONS.

Strengthen the shock-absorber fittings where failures occurred. These fittings should be redesigned to stand a load factor of 6, the required factor for the struts.

LEADING EDGE TEST.

DESCRIPTION OF SET-UP.

A 6-foot section was cut from the upper wing panel and mounted on a framework so that the main points of support were along the wing spars.

A counterbalance of lead shot bags was placed on the rear portion of the wing section to counterbalance the load placed on the leading edge.

The leading edge was then loaded in increments of 100 pounds and, as signs of failure were noticed, 50 pounds increments were added.

RESULTS.

When a load of 3,450 pounds was allowed to remain on for 1 minute, the leading edge sheared off.

Figure 31 shows the method of support and gives the computations.

CONCLUSION.

Since the failure occurred at a load factor of 16.3, the leading edge is amply strong.

TAIL SKID TEST.

DESCRIPTION.

The fuselage was attached at the front end to a jig and a load of 500 pounds placed and secured on the fuselage just over the tail skid. The fuselage was inclined to the left at an angle of 14° from the perpendicular. The rear portion of the fuselage was so coupled to a hoist that it could be raised and dropped suddenly.

PROCEDURE.

The tail skid withstood the first and second drop of 6 inches and 12 inches, respectively, without failure.

On the 18-inch drop one small crack was noticed on the tail skid and the fuselage twisted somewhat.

On being dropped 24 inches the tail skid and rear portion of fuselage both collapsed.

Figure 40 is a photograph of the failure.

DISCUSSION.

Even though the shock-absorber elastic functioned properly, the tail skid itself is too weak to stand the shock imposed upon it. The rear end of the fuselage is also very weak and not strong enough to withstand the torsion imposed by this particular test.

The required distance a tail skid must be able to drop without failure is 36 inches.

CONCLUSION.

The tail skid and rear of fuselage are both weak. The fuselage is too narrow to resist the torsion.

RECOMMENDATIONS.

Redesign tail skid, shock absorber, and rear of fuselage to withstand a 36-inch drop.

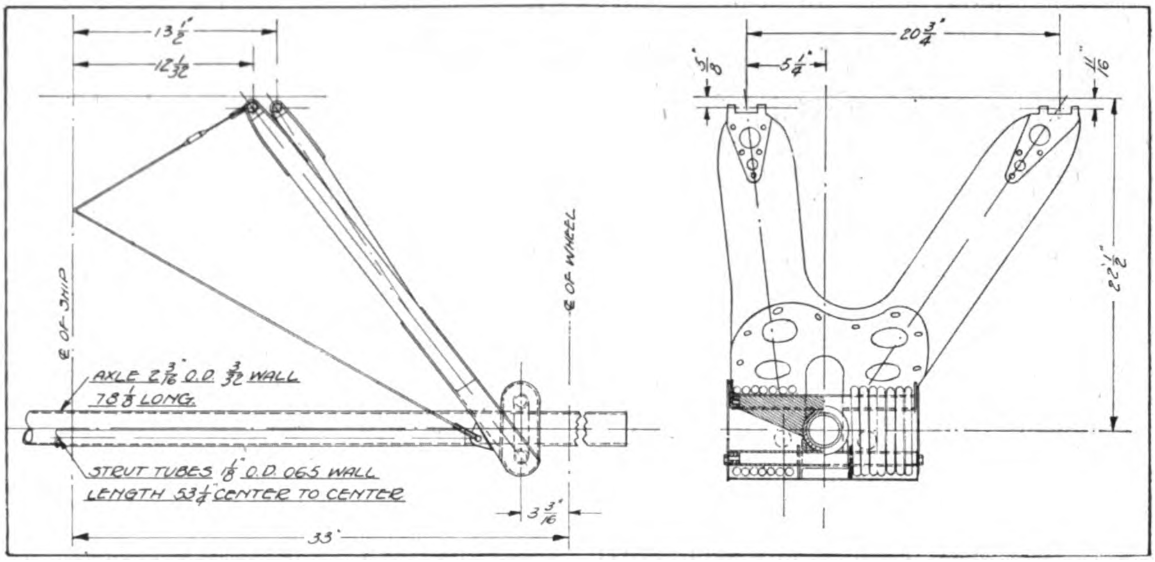
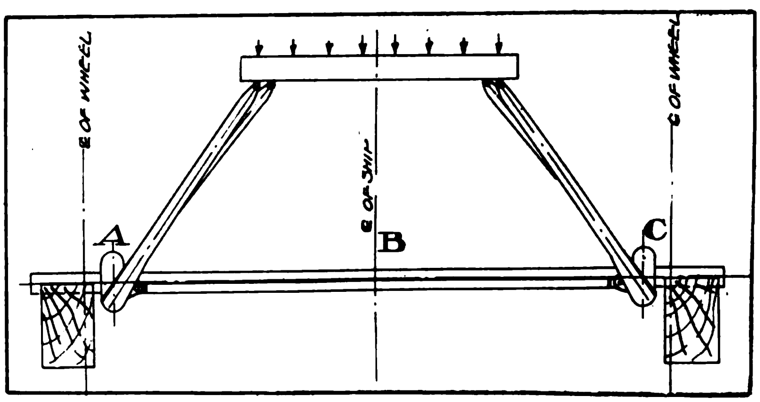


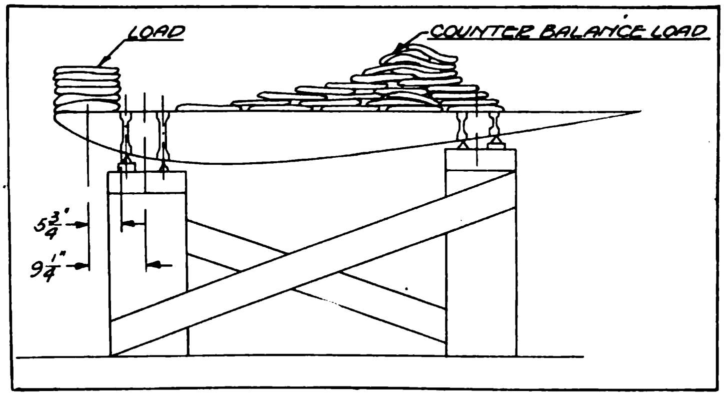
Fig. 29.—Landing chassis.



DEFLECTIONS AND RESULTS OF LANDING CHASSIS TEST.

Load factor.	Deflections at—			Load in pounds, factor.	Total load (pounds).	Remarks.
	A	B	C			
2	1 3/8	7/16	1 3/32"	6,641	6,641	
3	....	3/4	....	3,918	10,559	Shock absorber chords removed.
4	....	11/16	....	3,918	14,447	Held.
4.5	....	....	....	1,959	16,436	Struts on right-hand side sinking into fitting, strut deflecting, axle 1/16" set.
5	....	....	....	1,959	18,395	Failure of 5/16" bolts on right-hand side.
5.5	....	....	....	1,959	....	
6	....	....	....	1,959	....	Required factor.

Fig. 30.—Loading schedule and deflections for landing chassis.



TEST DATA.

The leading edge was loaded in accordance with the above sketch.
The load was increased until the total load on the leading edge was 3,450 pounds.
The structure supported this load for one minute when the failure occurred.
The leading edge sheared off at the face of the front spar.
Load for factor of 1=3,308 pounds load carried by upper wing 3,308×.7=2,315.6 pounds.
Load per foot run=2,315.6÷32,875=70.43 pounds.
Load for factor of 1 on leading edge=70.43÷2=35.21 pounds.
Load on leading edge causing failure=3,450 pounds.
3,450÷6=575 pounds=load per foot run causing failure.
$\frac{575}{35.21}$=16.32 factor at which leading edge failed.

FIG. 31.—Leading edge of wing test.

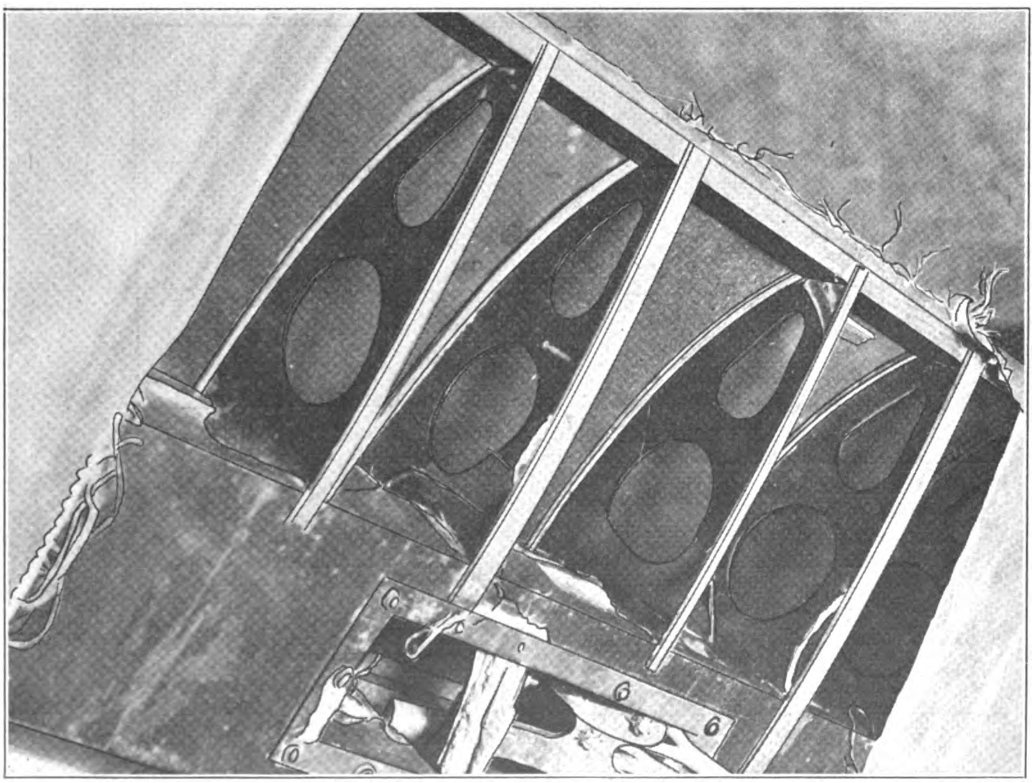


FIG. 32.—Spar and compression tube failure.

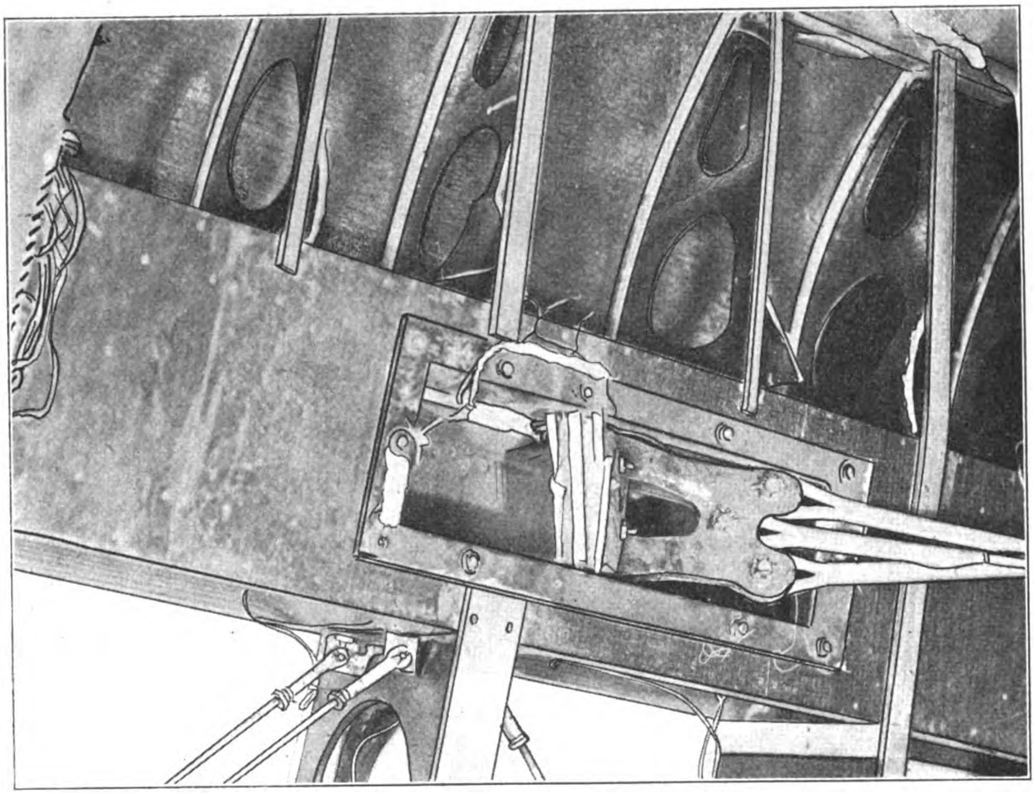


FIG. 33.—Spar and compression tube failure.

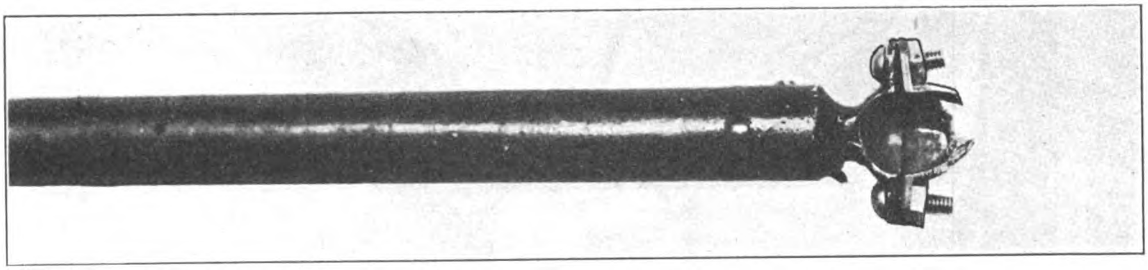


FIG. 34.—Ball joint failure

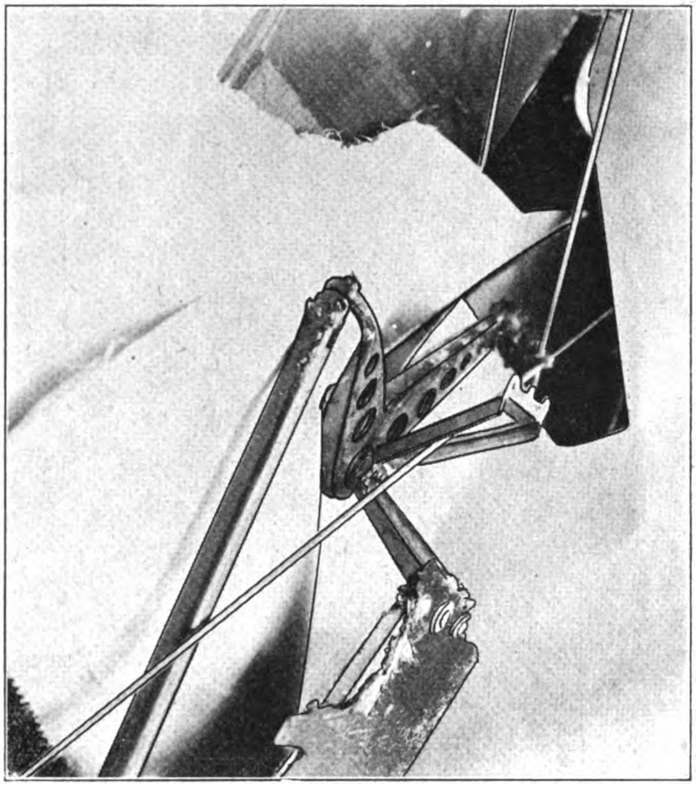


FIG. 35.—Ball crank failure.

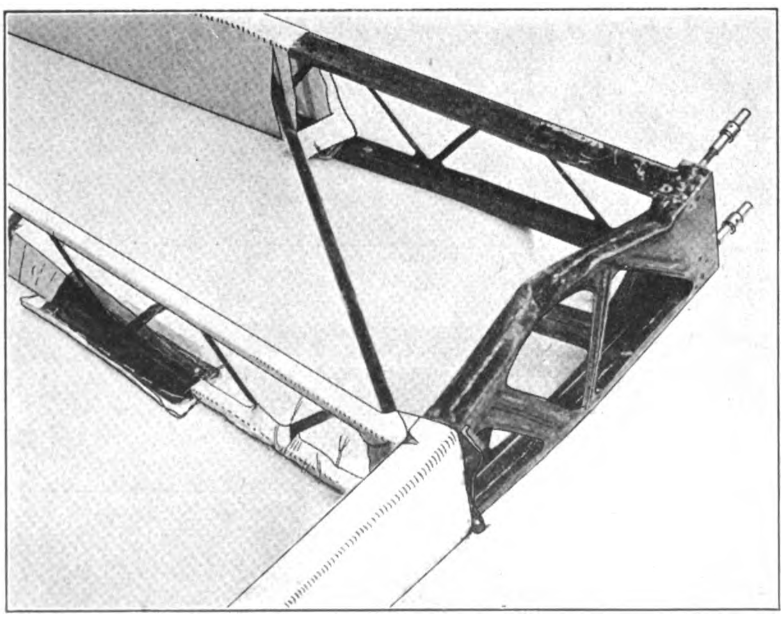


FIG. 36.—Failure of right stabilizer spar.

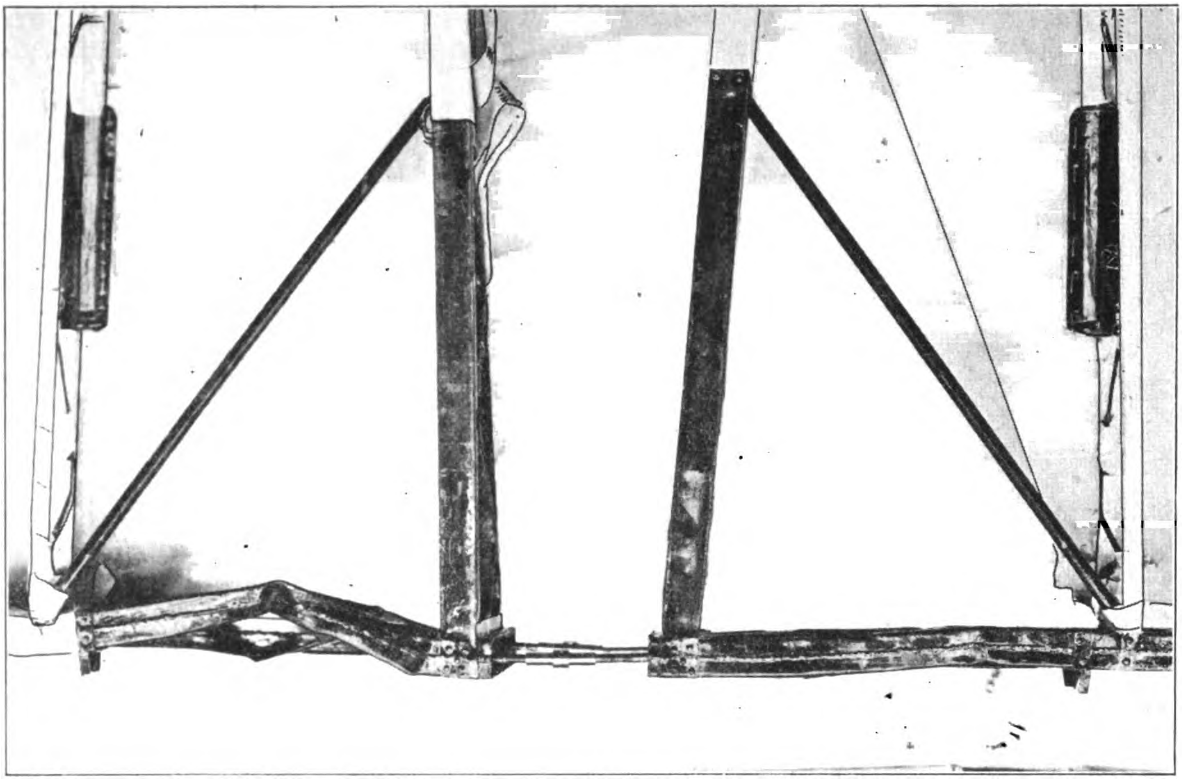


FIG. 37.—Failure of right and left stabilizer spars.

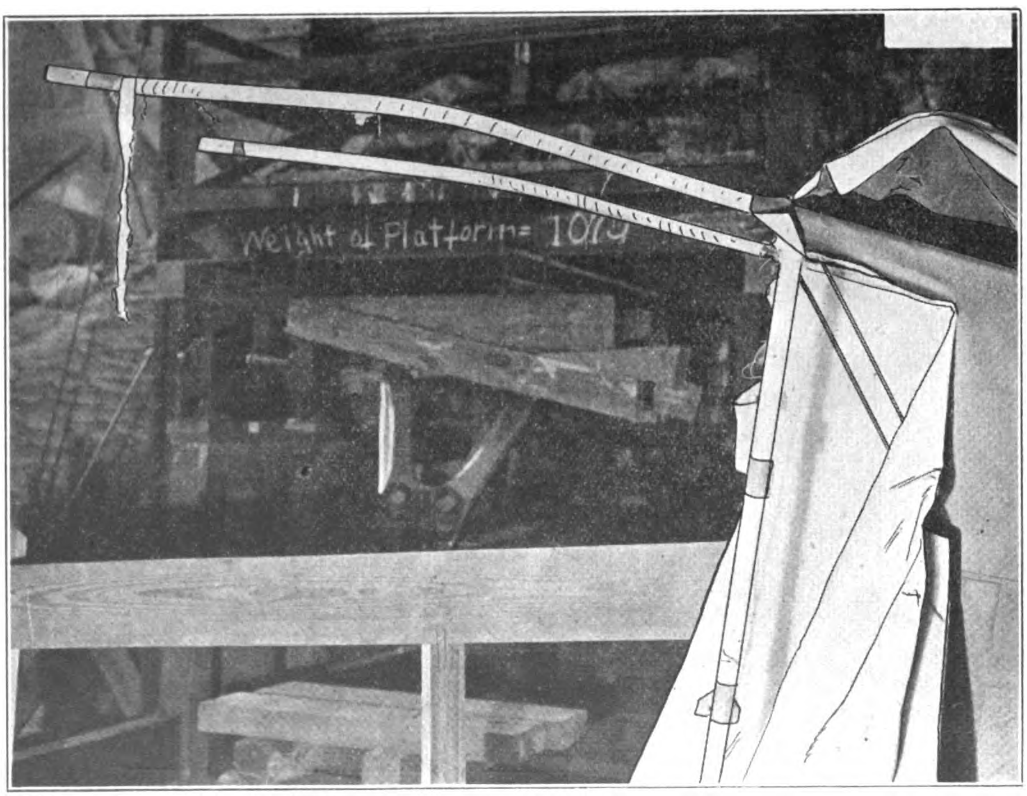


FIG. 38.—Lower longeron failure.

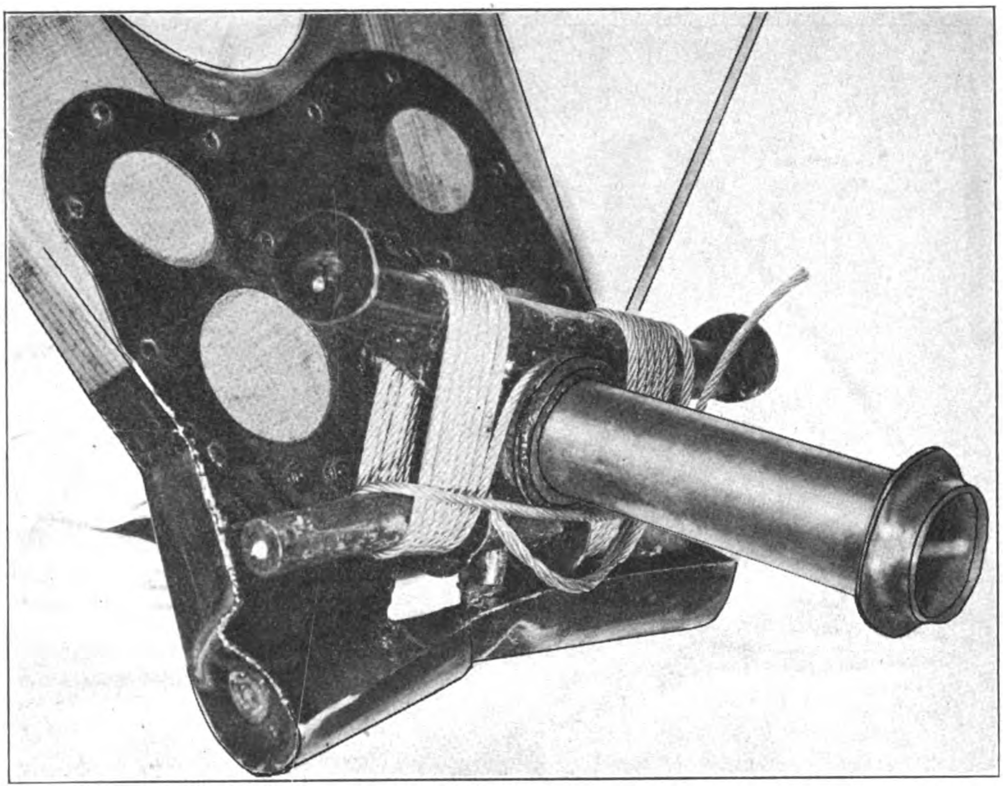


FIG. 39.—Landing gear failure.

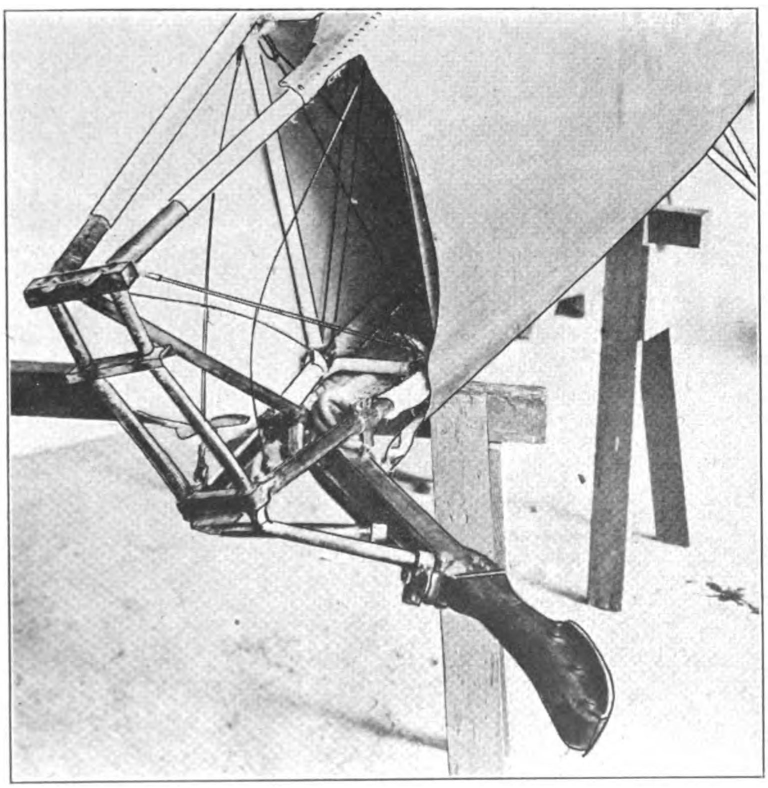


FIG. 40.—Tail skid failure.

91

File C71.6/152 *McCOOK FIELD REPORT, SERIAL No. 1893*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV September 1, 1922 No. 366

EMERGENCY LANDINGS FROM LOW ALTITUDES--MINIMUM ALTITUDE REQUIRED TO TURN BACK INTO FIELD IN CASE OF ENGINE FAILURE AFTER TAKE-OFF

(FLYING SECTION REPORT NO. 83)

Prepared by Louis P. Moriarty, First Lieut. A. S.
Engineering Division, Air Service
McCook Field, Dayton, Ohio
March 23, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

EMERGENCY LANDINGS FROM LOW ALTITUDES—MINIMUM ALTITUDE REQUIRED TO TURN BACK INTO FIELD IN CASE OF ENGINE FAILURE AFTER TAKE-OFF.

OBJECT OF INVESTIGATION.

An examination of records of accidents discloses the fact that a large percentage is due to the efforts of the pilot to turn back into the field when his engine fails on the take-off, without sufficient altitude to complete the turn. For each airplane there is a minimum altitude below which a complete 180° turn can not be made. The object of this investigation is to determine this altitude for various types.

SUMMARY OF RESULTS.

TABLE 1.—*Minimum altitudes for various types.*

Type.	Total weight.[1]	Minimum altitude.	Most efficient air speed.	Best angle of bank.	Radius of turn.
	Pounds.	*Feet.*	*M. P. H.*		*Feet.*
DH-4	4,297	340	75	45°	380
SE-5	2,058	270	70	45°	330
Curtiss JN4-H	2,200	230	60	45°	240
Thomas-Morse MB-3	2,548	400	78	45°	400
XB1-A	3,679	300	73	45°	360

[1] Full military load used in each case. If airplane is flown without full load, the altitude loss will be proportionately less.

The altitude given for each type should be taken as an absolute minimum for a complete turn of 180°, and can only be obtained by following fairly closely the air speeds and angles of bank which are recommended. Both theory and experiment point to the fact that a reasonable deviation from these conditions does not greatly increase the loss in altitude, and, with average piloting, an airplane can be turned back with safety at the altitudes shown in the table. On the other hand, even with exceptional piloting, these altitudes can not be appreciably decreased if a complete 180° turn must be made.

There is only one part of the maneuver in which a gain can be made, namely, the take-off itself. The pilot should so "play his field" on the take-off that a complete half turn will not be necessary.

DISCUSSION OF METHODS USED.

In the solution of this problem, recourse was had to both theory and experiment. Briefly, the method of attack was as follows: The minimum altitude lost in the turn, and the best combination of air speed, angle of bank, and radius of turn to give this minimum were computed from the airplane coefficients. Then the altitude lost was measured in actual flight.

Table 1 gives only altitudes which have been checked in flight. The agreement between the measured and computed values, however, is so close that estimates may be made for other types by means of the chart on the last page of this report. There was a discrepancy in the case of the Thomas-Morse, the computed value being almost 19 per cent lower than the measured value. In all other cases the check was well within the limit of error in instrument readings. A more complete discussion of the method of computation is given below.

MATHEMATICAL APPENDIX.

SYMBOLS USED.

H = Altitude lost in 180° turn.

V = Forward velocity of airplane in feet per second.

V_d = Vertical component of forward velocity in feet per second.

V_h = Horizontal component of forward velocity in feet per second.

θ = Angle of flight path with horizontal.

A = Area of wings in square feet.

d = Density of air in pounds per cubic foot.

K_y = Lift coefficient of whole airplane (absolute).

K_x = Drag coefficient of whole airplane (absolute).

r = Radius of turn in feet.

L = Total lift in pounds.

D = Total drag in pounds.

W = Total weight of airplane in pounds.

ANALYTICAL SOLUTION.

Figure 1 shows the forces acting on an airplane in a gliding turn. The drag D is balanced by the component of the weight in the direction of the flight path $W \sin \theta$. The resultant, R, of the lift, L, and the component of the weight perpendicular to the flight path, may be considered as an unbalanced force producing an acceleration toward the center of the turn.

The following relations are apparent from the figure:

(1) $\sin \Theta = V_d / V$

(2) $D = W \sin \Theta$

(3) $L^2 + W^2 \cos^2\Theta = R^2$

(4) $W \sin \Theta = Kx \frac{d}{g} A V^2$

(5) $W^2 \cos^2 \Theta + \frac{W^2}{g^2} \frac{V^4}{r^2} = Ky^2 \frac{d^2}{g^2} A^2 V^4$

(6) $V_d = \frac{K_x \, d \, A \, V^3}{g}$

Combining (4) and (5), and dividing by V^4, gives

(7) $\frac{K_x^2 \, d^2 \, A^2}{g^2 \tan^2 \Theta} + \frac{W^2}{g^2 \, r^2} = Ky^2 \frac{d^2}{g^2} A^2$

now

$$H = \pi \, r \tan \theta.$$

or

(8) $$\tan^2 \theta = \frac{H^2}{\pi^2 \, r^2}$$

For simplification, the following notation is introduced:

$$a = (d \, A \, \pi)^2$$
$$b = (d \, A)^2$$
$$c = W^2$$

Equation (10) becomes

(11) $$H^2 = \frac{a \, K_x^2 \, r^4}{b \, K_y^2 \, r^2 - c}$$

differentiating

(12) $$\frac{\delta H^2}{\delta r} = \frac{4 \, a(br^2ky^2 - c)K_x^2 r^3 - 2 \, abr^5kx^2ky^2}{(br^2ky^2 - c)^2} = 0$$

(13) $$\frac{\delta H^2}{\delta K_x} = \frac{2 \, a(br^2ky^2 - c)r^4kx - 2 \, abr^6kx^2kyky'}{(br^2ky^2 - c)^2} = 0$$

Combining (12) and (13), and simplifying

(14) $$r^3(ky^2 - k_xkyky') - r^2kx \, ky^2 - r\frac{c}{b} - 2\frac{c}{b}kx = 0.$$

Neglecting $r^2 \, kx \, ky^2$ and $2 \frac{c}{b} kx$, which are relatively small, and solving for r, we have

(15) $$r = \left(\frac{c}{b(ky^2 - kx \, ky \, ky')}\right)^{\frac{1}{2}} = \frac{W}{dA \, (K_y^2 - kx \, ky \, ky')^{\frac{1}{2}}}$$

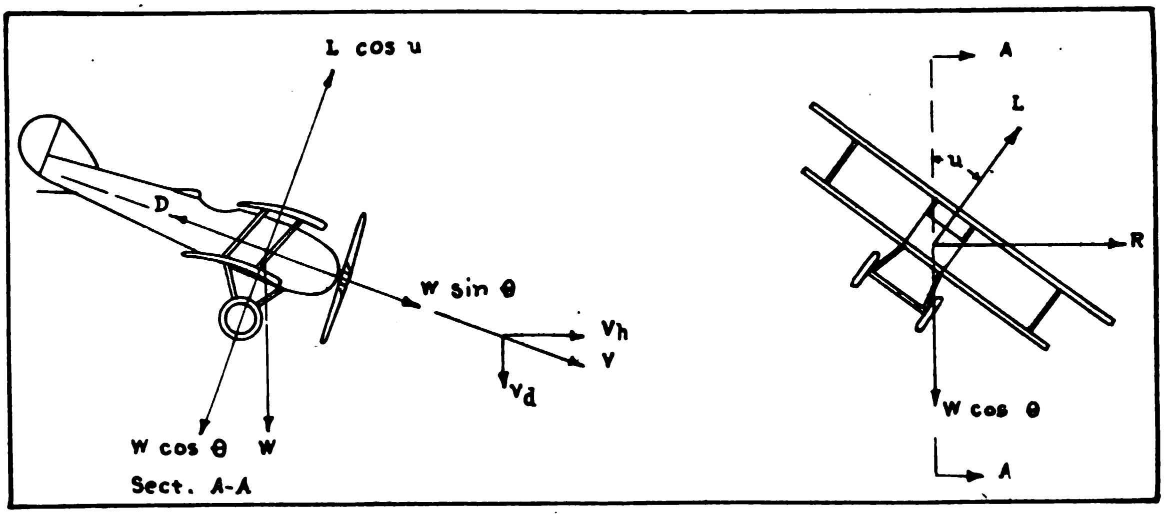


Fig. 1.

substituting in (7)

(9) $$\frac{K_x^2 \, d^2 \, A^2 \, \pi^2 \, r^2}{g^2 \, H^2} = K_y^2 \frac{d^2}{g^2} A^2 - \frac{W^2}{g^2 \, r^2}$$

or

(10) $$H^2 = \frac{K_x^2 \, d^2 \, A^2 \, \pi^2 \, r^4}{K_y^2 \, d^2 \, A^2 \, r^2 - W^2}$$

For a given airplane, flying in a given density, d, A and W are constant. The variables entering into equation (10) are therefore r, K_x and K_y. Of these three, r and K_x may be taken as independent variables, K_y being considered as a function of K_x. In order that H may be a minimum it is only necessary that

$$\frac{\delta H}{\delta r} = 0$$

and

$$\frac{\delta H}{\delta K_x} = 0$$

A solution of these two equations simultaneously will therefore give the radius of turn at which the least altitude will be lost as well as the best angle of incidence at which to fly during the turn.

Substituting in (10), and simplifying

(16) $$H^2 = \frac{\pi^2 W^2}{d^2 A^2} \cdot \frac{K_x^2}{(kx \, ky^3 \, ky' - kx^2ky^2ky'^2)}$$

This equation is of interest, as it brings out the fact that for a given combination of airplane coefficients, the altitude lost in a 180° turn is directly proportional to the wing loading and inversely proportional to the density.

Differentiating with respect to K_x, equating to 0, and simplifying, we have

(17) $$K_y^3ky' - 3 \, kx \, ky^2ky'^2 + 2 \, kx^2ky \, ky'^3 - kx \, ky^3ky'' + 2 \, kx^2ky^2ky'ky'' = 0.$$

We will now assume that ky can be expressed as a function of kx, of the form

(18) $$K_y = a + b \, kx + c \, kx^2$$

While such an expression will not hold true over the whole range of values of K_x, it will approximate the curve very closely over the range where the minimum value of H occurs.

Differentiating (18)

(19) $$ky' = b + 2 \, c \, K_x$$

(20) $$K_y'' = 2 \, c.$$

Substituting (18), (19), and (20) in (17) and collecting terms.

$$(21)\quad 12\, c^4kx^7+25\, bc^3kx^6+(16\, b^2c^2+8\, ac^3)\, kx^5+(3\, b^3c+3\, abc^2)\, kx^4-(4\, ab^2c+4\, a^2c^2)kx^3-(ab^3+5a^2bc)kx^2+a^3b=0$$

In this equation the constants a, b, and c can be found for any airplane whose lift-drag curve is known, and the equation can be solved for kx. This value of kx can then be substituted in equation (16) and the minimum value of H can be found.

For example, in the case of the DH-4

$$a=\ -.186$$
$$b=\ 15.27$$
$$c=-84.4$$

Substituting these values in equation (21) and solving, we find

$$Kx=.07$$

which can be substituted in equation (16), giving a value of H=260 feet.

A correction must now be made for the conditions at the beginning and end of the maneuver.

The recovery.—It has been found that the excess speed in the turn, which is usually from 15 to 20 miles per hour, can be used in coming out of the bank without loss in altitude. It is only necessary, then, to allow an altitude above the ground equal to one-half the span of the airplane in order to allow the lower wing to clear the ground. The average correction will be about 12 per cent of the total altitude.

A further arbitrary addition of 10 per cent will be added as a safety factor to allow for inaccuracies in piloting, making a total correction of 32 per cent.

With this correction the value of H for the DH-4 is 343 feet.

At first sight this method of correcting for conditions at the beginning and end of the maneuver may seem very approximate, but allowing an error as large as 25 per cent in each of the corrections, the probable error in the total altitude from this cause will be less than 5 per cent, which means an average error in altitude of only 15 feet. The final test of any assumption is the accuracy of the results which it gives, and except in the case of the Thomas Morse, as noted above, the agreement with the results of aletua tests has been very close.

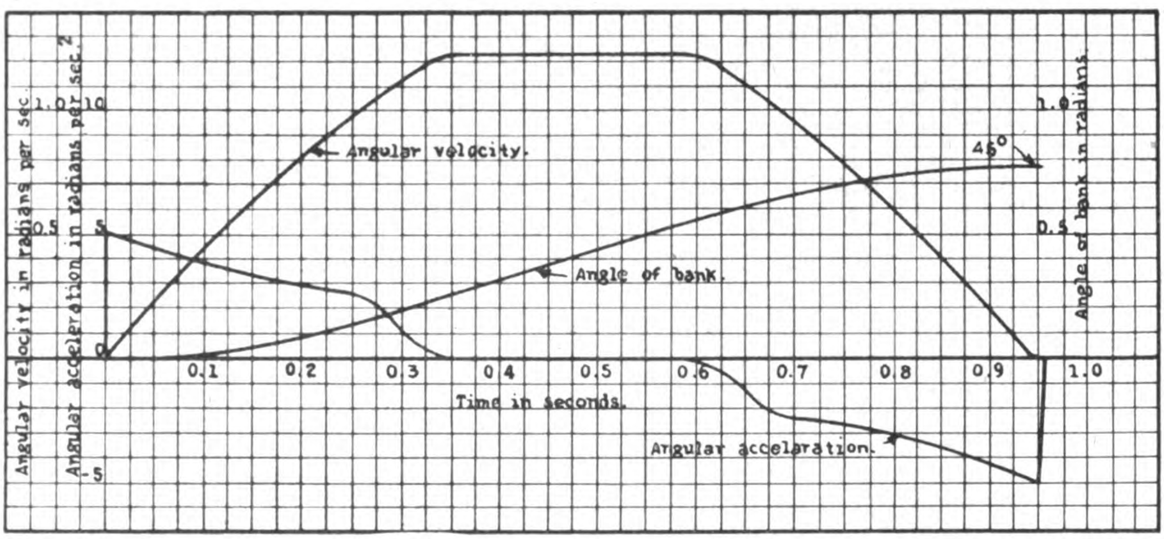


FIG. 2.—Lateral control, XB1-A. Showing angular velocities and accelerations during a bank of 45 degrees.

The start.—Immediately after the failure of the engine there is an interval during which the pilot must nose over to prevent stalling. During this time there is always a drop in air speed, which varies with the alertness of the pilot and the characteristics of the airplane. Tests were made to determine this drop in air speed under conditions simulating sudden engine failure, and the average drop for the DH-4 and the XB1-A was 5 miles per hour. The altitude lost in regaining this speed was computed as 14 feet for the DH-4, or 5 per cent of the total altitude.

In banking, there is a further loss of altitude. The time of bank from 0 to 45° was computed for the XB1-A by the method of step-by-step integration, using a computed lateral radius of gyration of 5.5 feet. The curves of angular velocity and angular acceleration are shown in Fig. 2. The computation gave 0.96 second to 45°, while a rough measurement in flight gave 1.1 seconds. Half of this time may be considered as not producing any turning. The total time for the turn being 11 seconds, the loss is 5 per cent of the total.

The above method is perfectly general, and can be applied to any airplane whose weight, wing area, and lift-drag curve are known. It is, however, very laborious, as it involves the solution of a seventh-degree equation. The following graphical method, while not as general, is much more easily applied and can be used for types equipped with R. A. F. 15 or sections of approximately similar characteristics.

GRAPHICAL SOLUTION.

Equation (18), between lift and drag coefficients will be used as the basis of the graphical solution:

$$(18)\qquad ky=a+b\, kx+c\, kx^2$$

For the DH-4

$$(22)\qquad ky=-.186+15.27\, kx-84.4\, kx^2$$

A plot of this equation is shown in Fig. 3. It will be noted that the agreement with the experimental results is very good, except in the region of maximum ky. At $kx=.07$, where the minimum value of H occurs, the empirical curve agrees in slope and location with the actual curve.

For any other given type equipped with R. A. F. 15 section it is assumed that the difference between its drag and the drag of the DH-4 is a constant for all values of ky, that is,

$$(23) \qquad kx_1=kx+K$$

(Subscripts refer to any given type other than DH-4.)

The value of K depends upon the parasite areas of the two types.

$$(29) \quad K=0.64\left[\left(\frac{Ae}{A}\right)_1-\left(\frac{Ae}{A}\right)\right]$$

Ae=equivalent flat plate area of parasite resistance.

For the DH-4,

$Ae=14$

$A=440$

$\frac{Ae}{A}=.0318$

Information is available on the equivalent parasite area of most types which have been flight-tested at McCook Field. It is more convenient, however, to use fineness

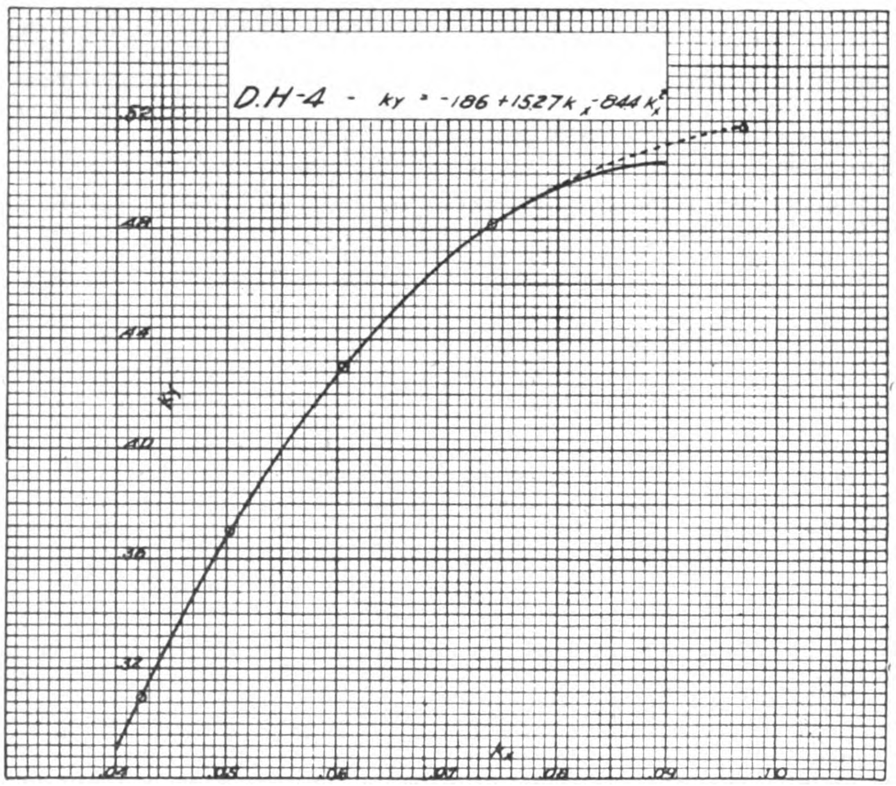


FIG. 3.

Equation (18) will be of the form:

$$(24) \qquad ky=a_1+b_1kx_1+c_1kx_1^2$$

Substituting (23) in (24)

$$(25) \quad ky=a_1+b_1kx+b_1K+c_1Kx^2+2c_1Kkx+c_1K^2$$

Combining (18) and (25), and equating coefficients of like powers of kx,

$$(26) \quad a_1=a-bK+cK^2$$

$$(27) \quad b_1=b-2cK$$

$$(28) \quad c_1=c$$

as a parameter, fineness being a function of $\frac{Ae}{A}$. The following table gives the values of $\frac{Ae}{A}$, K, and the coefficients of equation (24), for various values of fineness:

TABLE 2.

Fineness.	$\frac{Ae}{A}$	K	a_1	b_1	c_1
90	.050	.01164	−.3754	17.23	−84.4
100	.0326	.000512	−.1938	15.36	−84.4
110	.0225	−.00595	−.0980	14.27	−84.2
120	.0153	−.01055	−.0343	13.49	−84.1

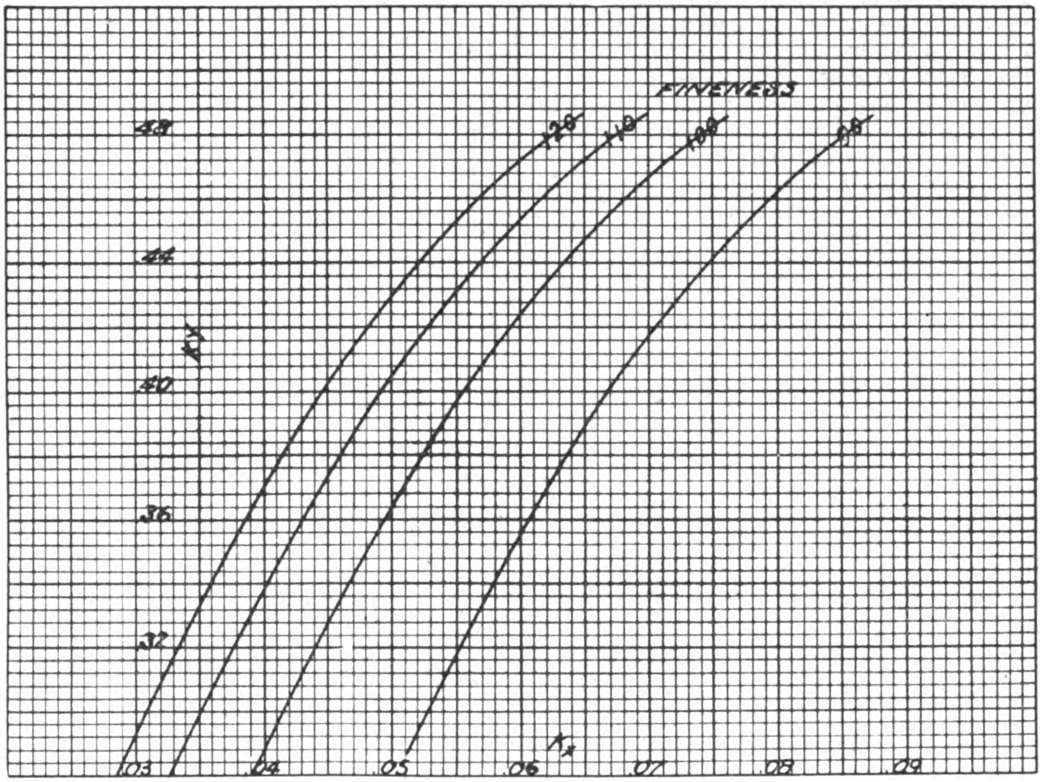

FINENESS
120
110
100
90
48
44
40
36
32
Ky
Kx
.03
.04
.05
.06
.07
.08
.09

FIG. 4.

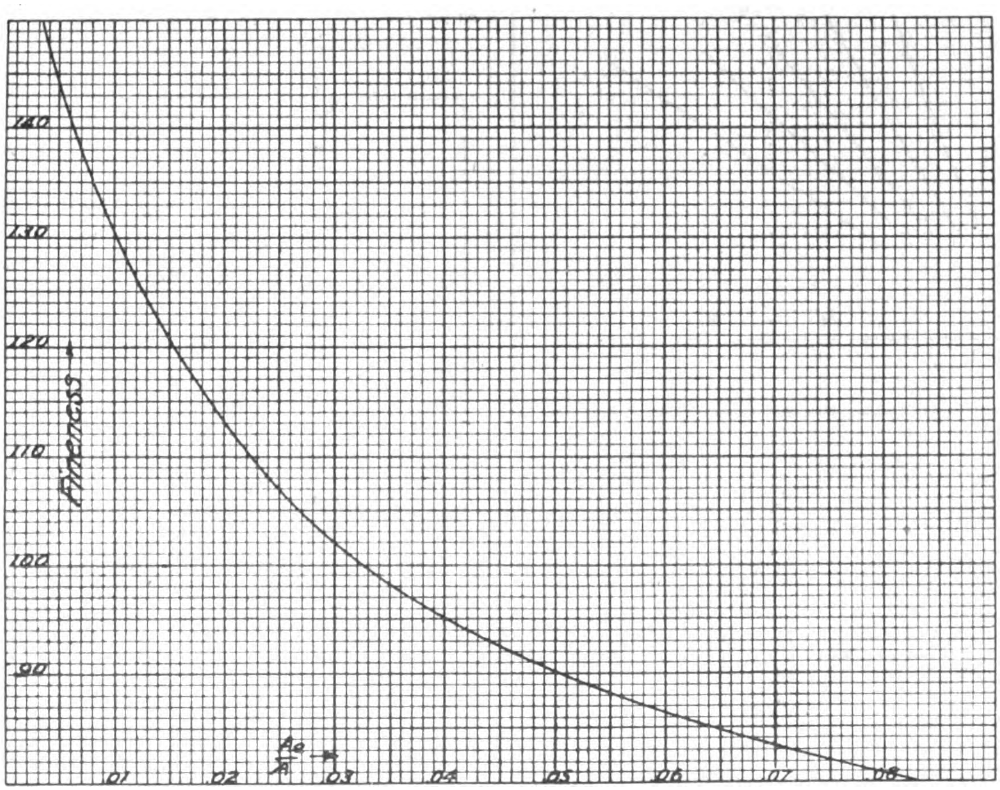

140
130
120
110
100
90
Fineness
.01
.02
.03
.04
.05
.06
.07
.08

FIG. 5.

Fig. 4 shows polar diagrams for various finenesses. It is realized that these curves are approximations, since they are based on the assumption of equation (23).

This same method of attack has, however, been used in the Kerber method of performance prediction,[1] and has given excellent results. A report containing a complete discussion of the relation between fineness and parasite area, and of the method of determination of fineness with any air foil is now being prepared by Mr. Kerber, and will be published within a short time.

The relation between fineness and $\frac{Ae}{A}$ is shown in Fig. 5.

From equation (16),

$$H=\frac{W}{d\,A}\,\frac{K_x}{K_y(kx\,ky\,ky'-K_x^2K_y'^2)^{\frac{1}{2}}}$$

Assuming standard density of 0.0761 pounds per square foot,

(30) $$H=41.2\frac{W}{A}f$$

where

$$f=\frac{K_x}{K_y\,(kx\,ky\,ky'-K_x^2k_y'^2)^{\frac{1}{2}}}$$

Equation (30) may be plotted with H and f as coordinates and $\frac{W}{A}$ as a parameter, giving a series of radiating straight lines, as shown symbolically in Figure 6. Section (2) of Figure 10 is plotted in this manner.

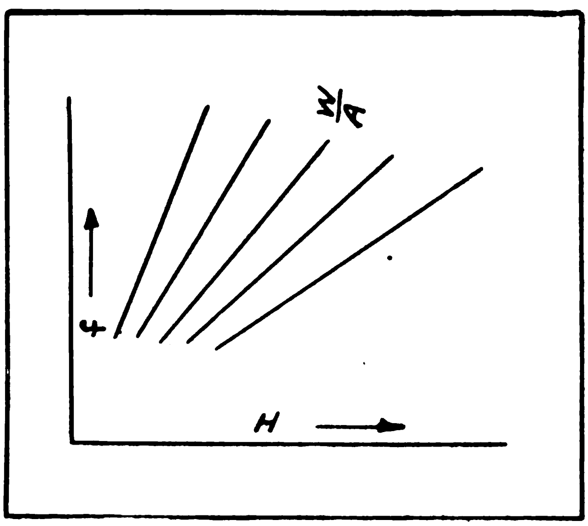


Fig. 6.

Rewriting equation (15),

$$r=\frac{W}{d\,A(K_y^2-Kx\,ky\,ky')^{\frac{1}{2}}}$$

or

(31) $$r=13.1\frac{W}{Af'}$$

where

$$f'=(K_y^2-kx\,ky\,ky')$$

Combining equations (30), (31), and (8),

(32) $$H=r\,ff'$$

which may be plotted as shown in Figure 7.
(See section (4) of chart on page 10.)

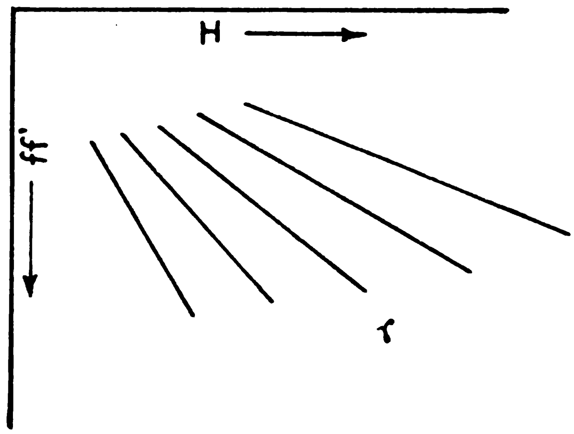


Fig. 7.

Rewriting equation (4),

$$V=\frac{W^{\frac{1}{2}}}{A}\left(\frac{\text{Sin}\,\theta\,g}{K_x\,d}\right)^{\frac{1}{2}}$$

or

(33) $$V=\frac{W^{\frac{1}{2}}}{A}f''$$

where

$$f''=\left(\frac{\text{Sin}\,\theta\,g}{K_x\,d}\right)^{\frac{1}{2}}$$

which may be plotted as shown in Figure 8.
(See section 6 of fig. 10.)

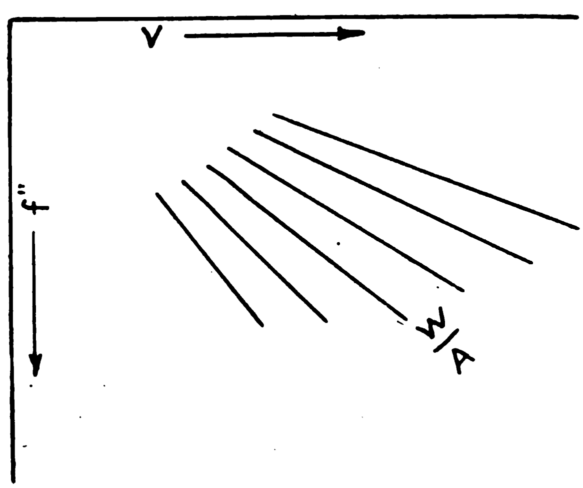


Fig. 8.

Let u = angle of bank

(34) $$\tan u=\frac{V^2}{g\,r}$$

(Actually, V_h^2 should be used, but the slight increase in accuracy does not justify the added complication.)

Substituting (31) and (33) in (34),

(35) $$\tan u=.00237\,f'f''^2.$$

[1] See Air Service Information Circular, Vol. II, No. 183.

The quantities f, f', and f'' are functions of the lift and drag coefficients. In Table 2, fineness has also been shown to be a function of these coefficients. That is:

$$f''=f_1\,(K_x, K_y)$$
$$f'f''^2=f_2\,(K_x, K_y)$$
$$F=f_3\,(K_x, K_y)$$

We have here three equations in five variables. An elimination of any two would give one equation in three variables. For example, an elimination of K_x and K_y would give a relation between F, $f'f''^2$ and f'', which could be plotted as shown in Figure 9.

Section 5 of Figure 10 is obtained in this manner, except that the abscissae are angles of bank instead of values of the function $f'\,f''^2$. This same line of reasoning applies to sections (1) and (3).

It will be noted that plotting by this method would be an extremely complicated process, owing to fact that no simple analytical expression can be found for the relationship of Figure 9. In the actual construction of the chart, the computations were greatly simplified by reversing the process. For each fineness, values of K_y were computed for various values of K_x, by use of equation (24) and Table 2. The functions f, f', etc., were then computed for these values of the coefficients, and corresponding values of H, r, and V were found.

In using the chart, it is only necessary to know the wing loading and the fineness. If the fineness is not known, it can be found from the high speed of the airplane, as outlined in Air Service Information Circular, Vol. II, No. 183,

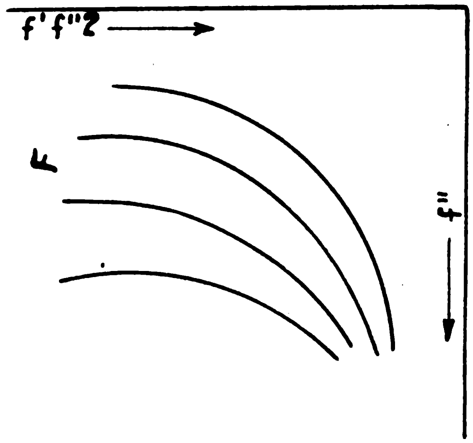


Fig. 9.

or, if the parasite resistance is known, fineness can be found by use of Figure 5. Knowing the fineness and wing loading, and assuming an angle of bank (45 degrees will give best results), H, r, and V can be found as shown by the dotted example line.

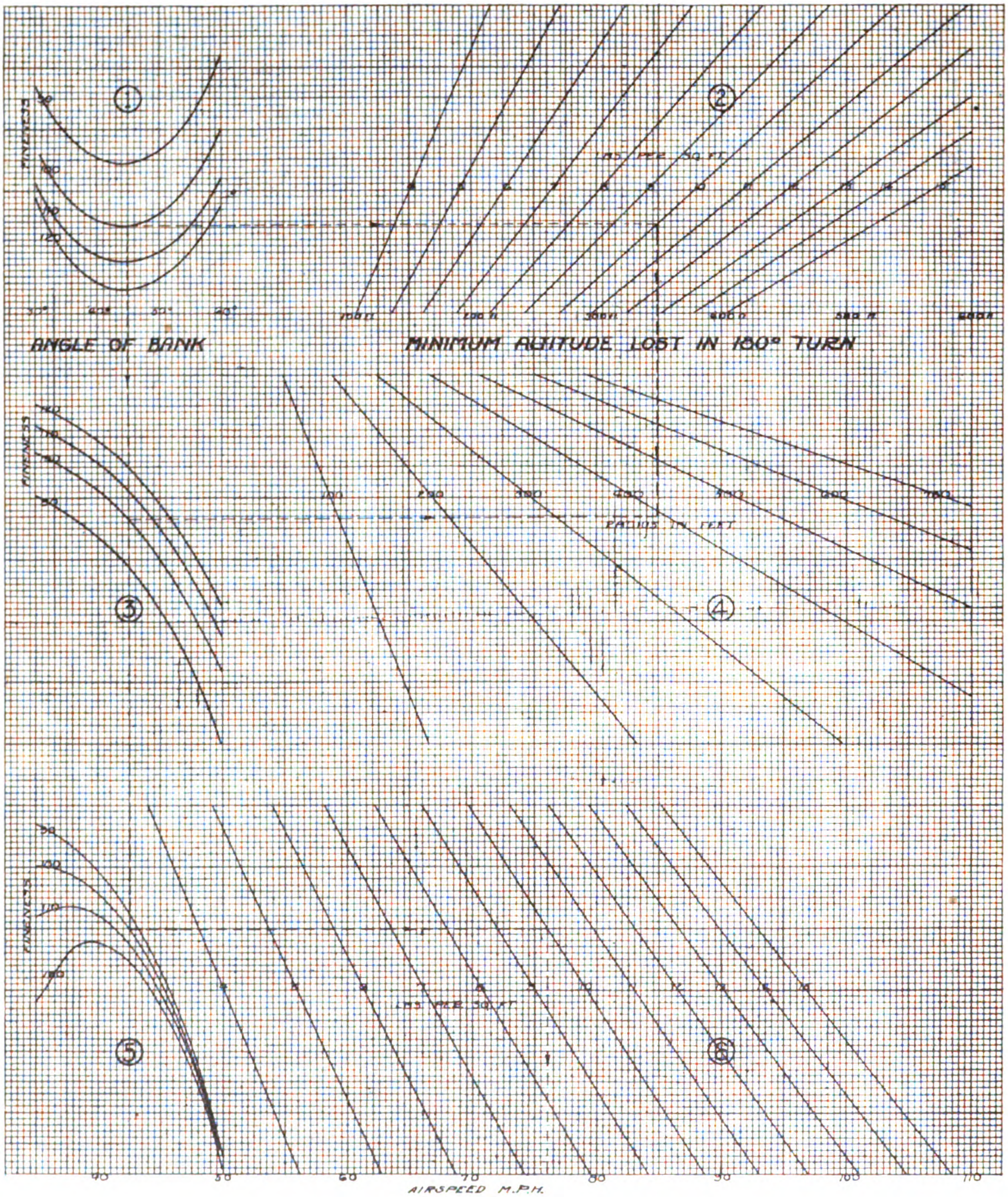


Fig. 10.—Chart for prediction of minimum altitude lost in 180° turn.

File D 52.1 / Junker-6 / 10 McCOOK FIELD REPORT, SERIAL No. 1898

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV September 1, 1922 No. 367

WIND TUNNEL TEST OF THE JUNKER L-6 MONOPLANE

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by F. W. Herman
Engineering Division, Air Service
McCook Field, Dayton, Ohio
April 3, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

Certificate: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

REPORT OF WIND TUNNEL TEST OF THE JUNKER L-6 MONOPLANE.

OBJECT OF TEST.

A 1/30 scale model of the JL-6 monoplane was constructed at McCook Field and tested at Massachusetts Institute of Technology during April, 1921, at a velocity of 30 miles per hour. Tests were run at six different elevator settings, −10°, −5°, 0°, +5°, +10°, and +15°. Lift, drag, L/D, and moment about center of gravity were determined. The wing alone was tested at 30 miles per hour to determine lift, drag, L/D, center of pressure, and moment coefficient at various angles of attack from −8° to +20°. In addition, a number of runs were made, using the tail as an exploring plane, to determine the influence of the body on the down wash. Angle of attack is measured between the wing chord and the wind in every case. All runs on the model were made with the stabilizer set at 0° to the thrust line. Elevator and stabilizer settings refer to thrust line.

RESULTS.

With the elevator at 0° the maximum L/D is 7.3. The ratio of maximum lift to minimum drag is 21.65. Maximum L/D occurs at angle of attack of 5½°, maximum lift at 17°, and minimum drag at −3°. With the stabilizer and elevator at 0° to the thrust line, the model does not balance at any angle of attack for which it was tested, but is slightly tail heavy. A small positive angle of attack of the tail plane would be necessary to secure balance.

The results on the wing alone show a maximum L/D of 13.6, a maximum Ky of 0.00377, and a minimum Kx of 0.000071. The ratio of maximum lift to minimum drag is 53.1.

The down-wash tests show that the rather unusual bump in the moment curve of the model is due to the blanketing of the tail by the body at high angles of attack. This bump begins at about 12° angle of attack and reaches a maximum at about 16°. The bump did not occur when a test was run with the tail and wings in their proper positions, but without the body.

Tables 1 to 6, inclusive, give the numerical results, and Figures 1 and 2 the graphical results of the complete model. Table 7 gives the numerical results and Figures 3, 4, and 5 show the graphical results for the wing alone. Tables 8 to 12, inclusive, give the numerical results and Figures 6, 7, and 8 show the graphical results of the down-wash experiment. Table 13 compares the wing alone to the U. S. A.-27 wing. Figure 13 is a three-view drawing of the model.

DISCUSSION.

The L/D for the model has a double maximum, one at 5½° and the other at 16°. The L/D hold a high value over a considerable range of angles of attack. It does not fall below 6.3 from +1½° to 17°. The moment curve for the model is rather unusual in the fact that it is nearly independent of angle of attack from −6° to +12°. This is true at elevator settings from −10° to +5°. At about 12° angle of attack a critical point occurs in the moment curve, the cause of which is discussed under down wash. From the critical point the curve rises rapidly to a maximum value at about 17° angle of attack.

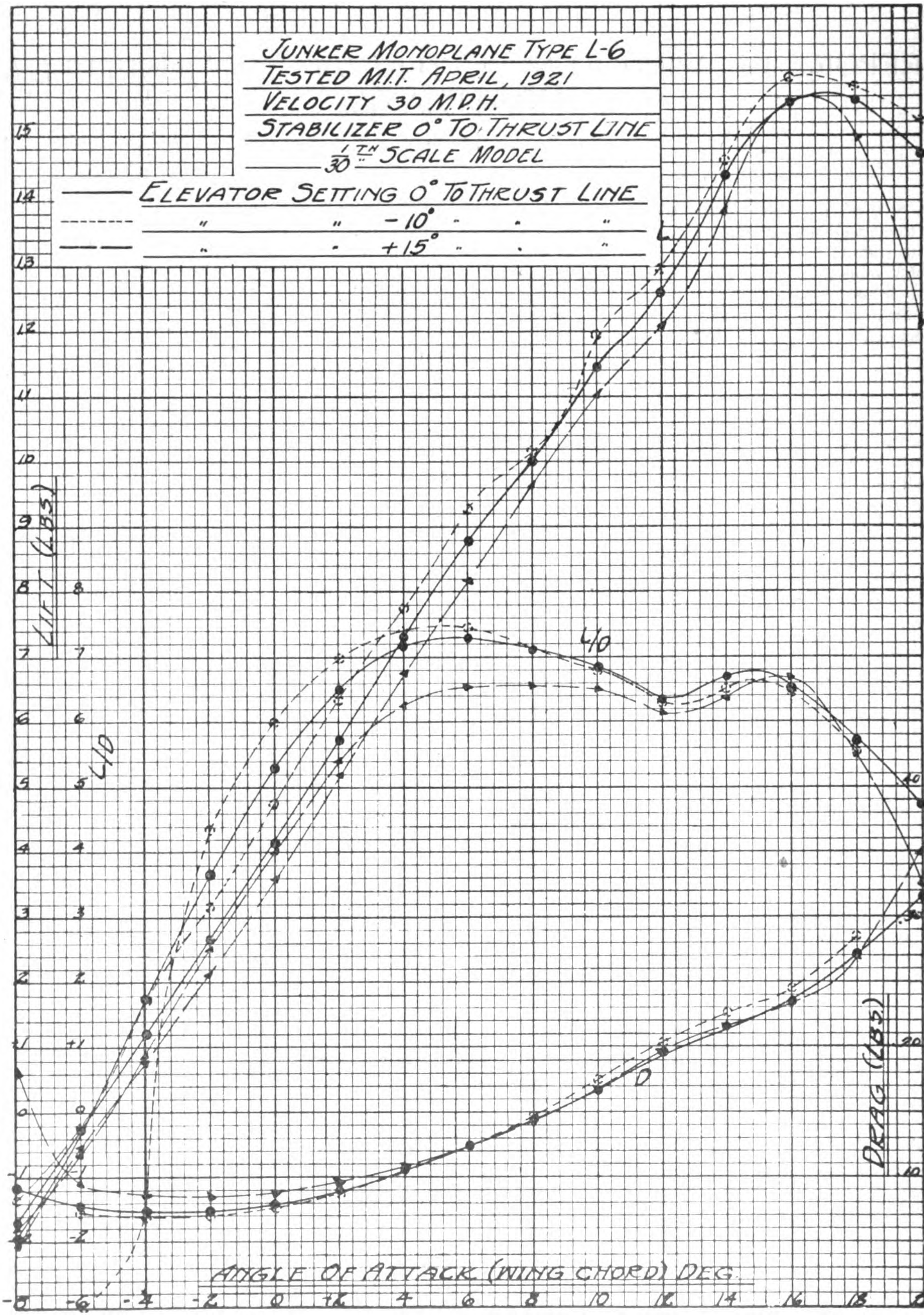
The test of the wing alone shows no unusual features.

DOWN WASH ON THE JUNKER L-6 MONOPLANE.

Due to the critical point in the moment curve of the pitching moment about the center of gravity for the Junker L-6, it was thought it would be of interest to investigate the down wash due to both the body and wings for this model. To determine the down wash due to the wings alone, the model was supported in the presence of the wing as shown in Figure 14, and the tail surface was turned for each incidence setting of the wing to the angle of zero lift. As the angle of zero lift for the tail alone had already been determined by previous test, the angle of down wash due to the wings was found by subtraction. To determine the down wash on the tail due to combination of body and wings, the model was supported as indicated in Figure 15. The tail again was on the movable head of the balance and the model and wings were mounted as before. The wing incidence was changed as in the previous case and the angle of zero lift on the tail noted. The angle of down wash is as before the difference between the angular setting required to obtain zero lift when the tail is tested alone and when tested in presence of the wing and body. The tail in both cases was used as an exploring plane. In Figure 7 the results of the two aforementioned experiments have been plotted, the wing incidence being plotted against the down-wash angle. It is to be noted that the down wash for the wings alone behaves in an ordinary fashion, but that the down wash due to the wings and body has a critical point at 12°. This confirms the belief that the body is undoubtedly the factor which causes the critical point in the pitching moment curves.

There has been plotted in this same figure a curve indicated as calculated down wash. This calculation is explained on page 15. It does not, however, allow for the slowing of the wind speed in the proximity of the tail due to the presence of the wings and body. The curves noted as experimental down wash are correct in that they allow for the presence of the wings and body, but unfortunately the effect of the propeller slipstream is ignored. This is an important factor, and it is hoped that at some future time facilities will permit of an investigation of the combined effect of propeller, wing, and body down wash on the tail.

In Figure 8 the lift coefficient for the Junker L-6 wing section has been plotted against the down-wash angle.



JUNKER MONOPLANE TYPE L-6
TESTED M.I.T. APRIL, 1921
VELOCITY 30 M.P.H.
STABILIZER 0° TO THRUST LINE
1/30 TH SCALE MODEL
ELEVATOR SETTING 0° TO THRUST LINE
" " -10° " " "
" " +15° " " "
LIFT (LBS)
L/D
DRAG (LBS)
ANGLE OF ATTACK (WING CHORD) DEG.
L
L/D
D

FIG. 1.

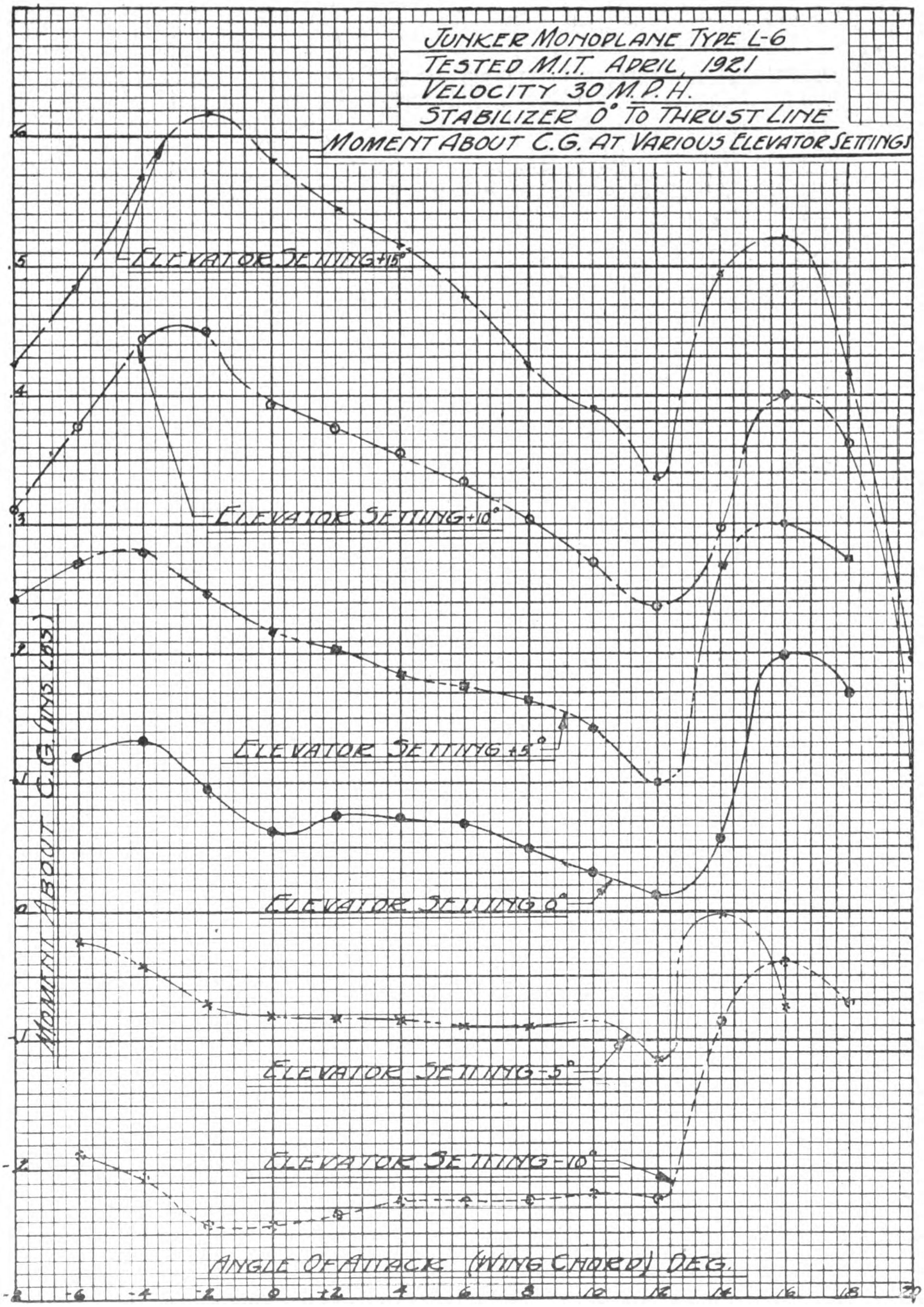

JUNKER MONOPLANE TYPE L-6
TESTED M.I.T. APRIL, 1921
VELOCITY 30 M.P.H.
STABILIZER 0° TO THRUST LINE
MOMENT ABOUT C.G. AT VARIOUS ELEVATOR SETTINGS
ELEVATOR SETTING +15°
ELEVATOR SETTING +10°
ELEVATOR SETTING +5°
ELEVATOR SETTING 0°
ELEVATOR SETTING -5°
ELEVATOR SETTING -10°
MOMENT ABOUT C.G. (INS LBS)
ANGLE OF ATTACK (WING CHORD) DEG.
6
5
4
3
2
1
0
-1
-2
-8
-6
-4
-2
0
+2
4
6
8
10
12
14
16
18
20

FIG. 2.

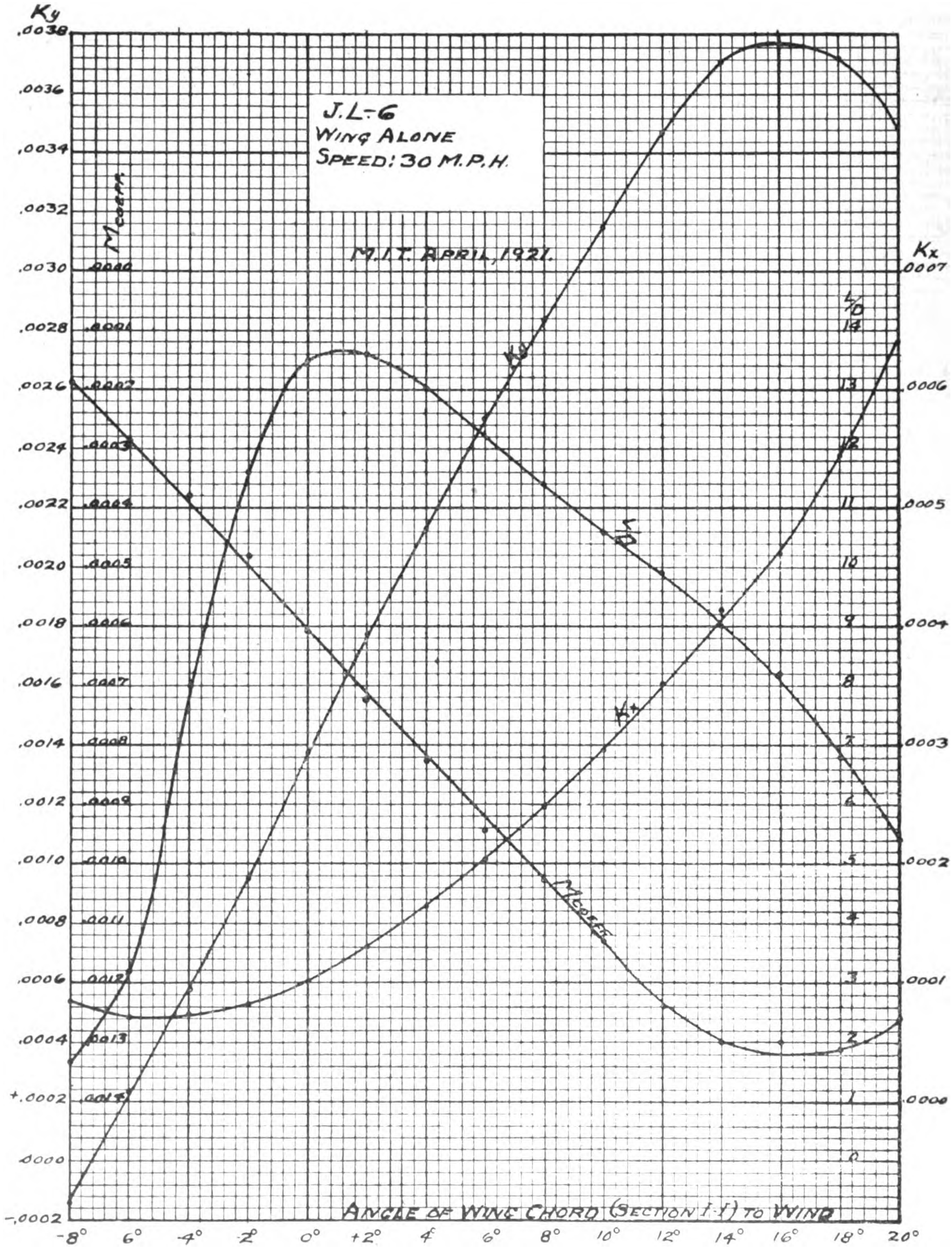
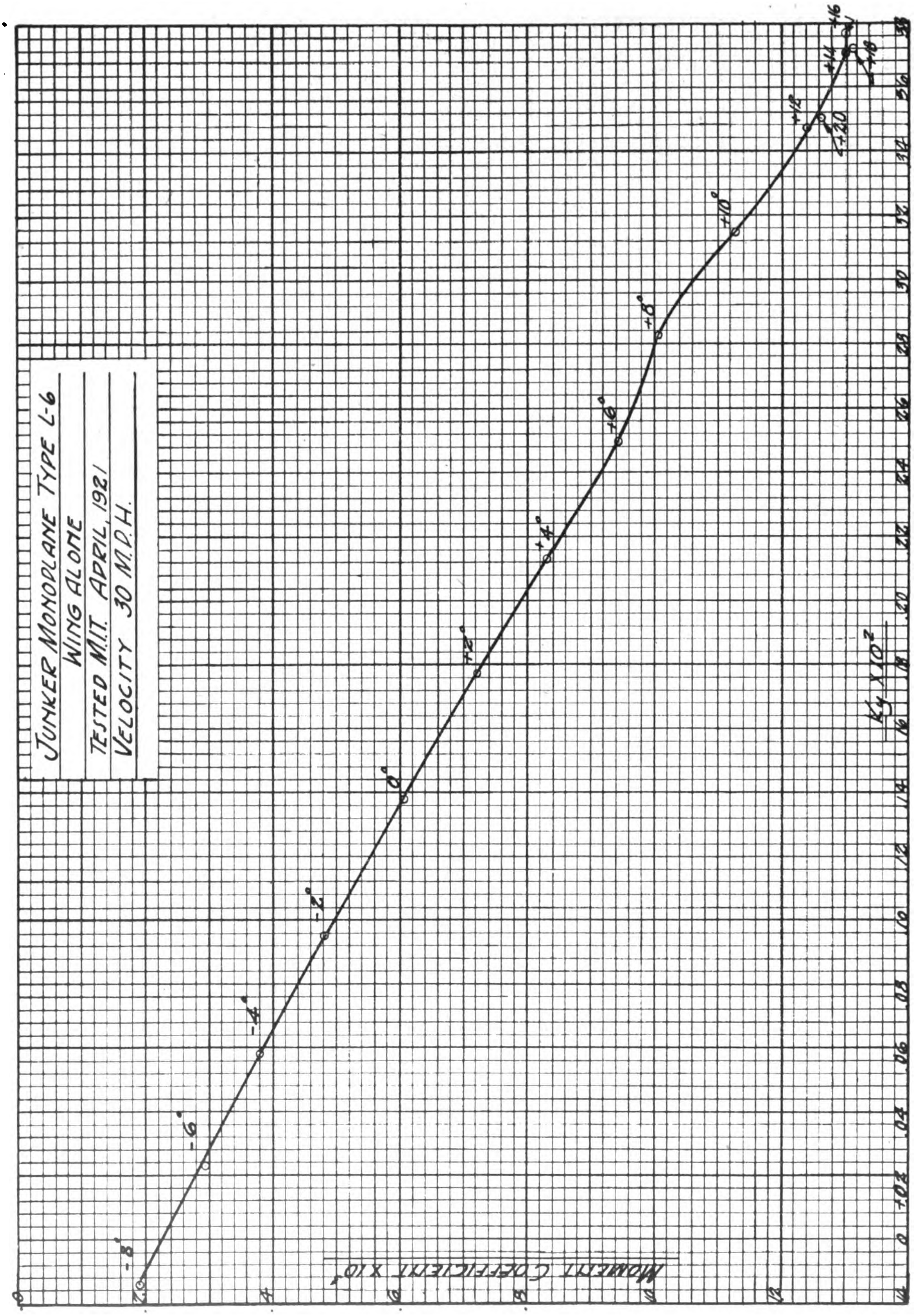

J.L-6
WING ALONE
SPEED: 30 M.P.H.
M.I.T. APRIL, 1921.
Ky
Kx
L/D
Mcoeff.
ANGLE OF WING CHORD (SECTION I-I) TO WIND
.0038
.0036
.0034
.0032
.0030
.0028
.0026
.0024
.0022
.0020
.0018
.0016
.0014
.0012
.0010
.0008
.0006
.0004
+.0002
.0000
-.0002
.0007
.0006
.0005
.0004
.0003
.0002
.0001
.0000
-8°
6°
4°
2°
0°
+2°
4°
6°
8°
10°
12°
14°
16°
18°
20°

FIG. 3.



JUNKER MONOPLANE TYPE L-6
WING ALONE
TESTED M.I.T. APRIL, 1921
VELOCITY 30 M.P.H.
Ky X 10²
MOMENT COEFFICIENT X 10²

Fig. 4.

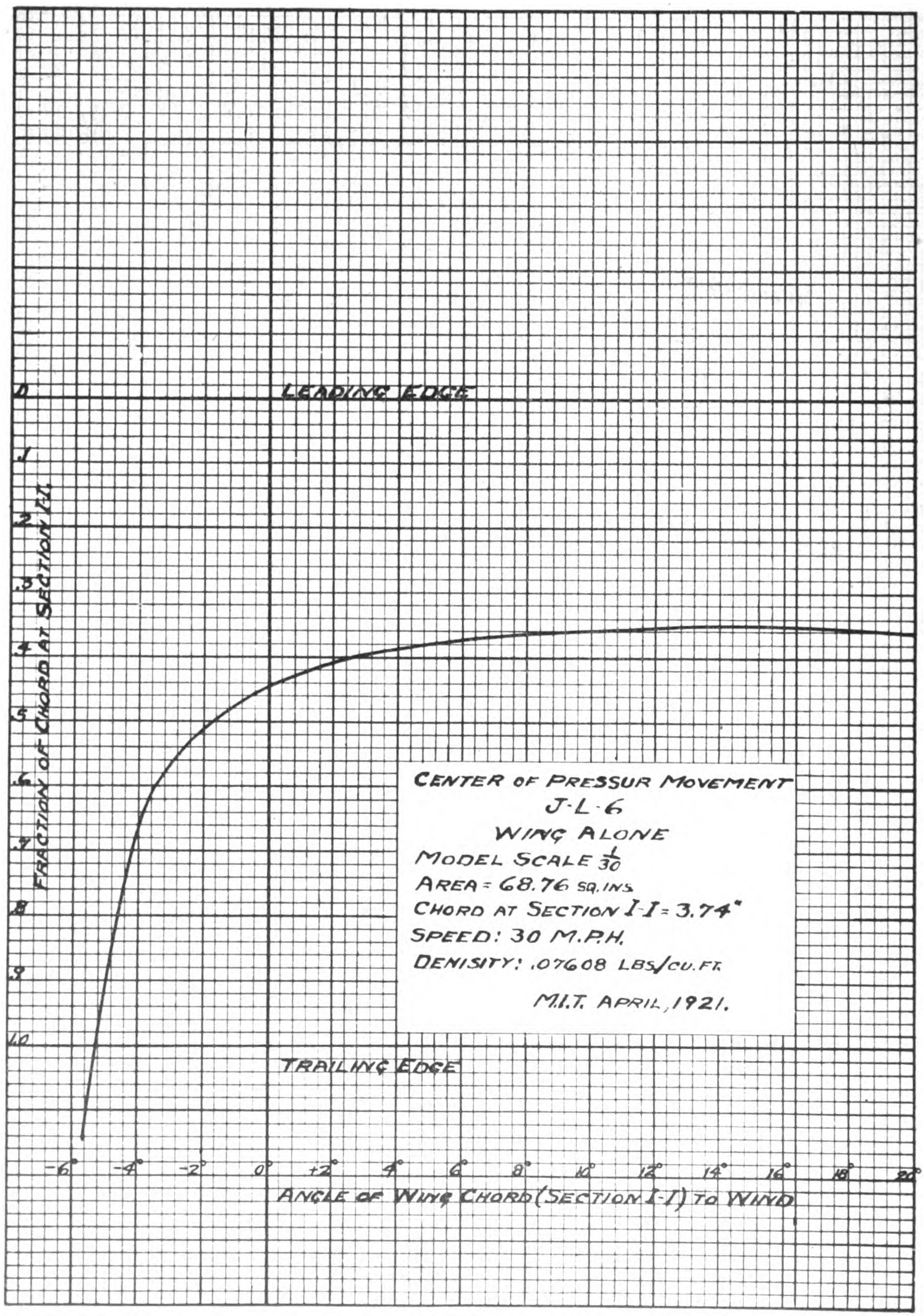

LEADING EDGE
TRAILING EDGE
FRACTION OF CHORD AT SECTION I-I
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
-6°
-4°
-2°
0°
+2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
ANGLE OF WING CHORD (SECTION I-I) TO WIND
CENTER OF PRESSUR MOVEMENT
J-L-6
WING ALONE
MODEL SCALE 1/30
AREA = 68.76 SQ. INS
CHORD AT SECTION I-I = 3.74"
SPEED: 30 M.P.H.
DENISITY: .07608 LBS/CU.FT.
M.I.T. APRIL, 1921.

FIG. 5.

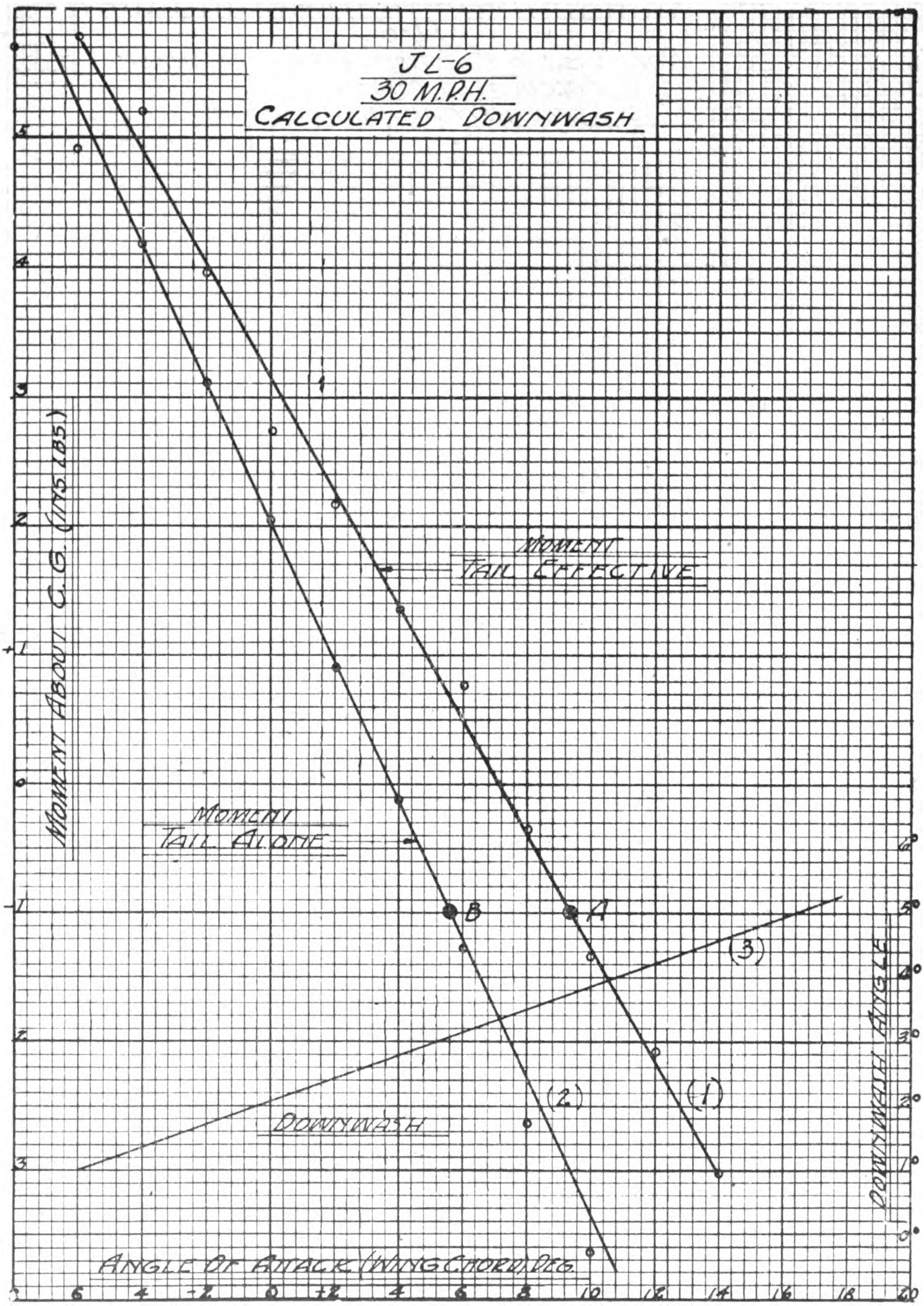

JL-6
30 M.P.H.
CALCULATED DOWNWASH
MOMENT TAIL EFFECTIVE
MOMENT TAIL ALONE
DOWNWASH
MOMENT ABOUT C. G. (175 LBS)
DOWNWASH ANGLE
ANGLE OF ATTACK (WING CHORD) DEG.
B
A
(1)
(2)
(3)

FIG. 6.

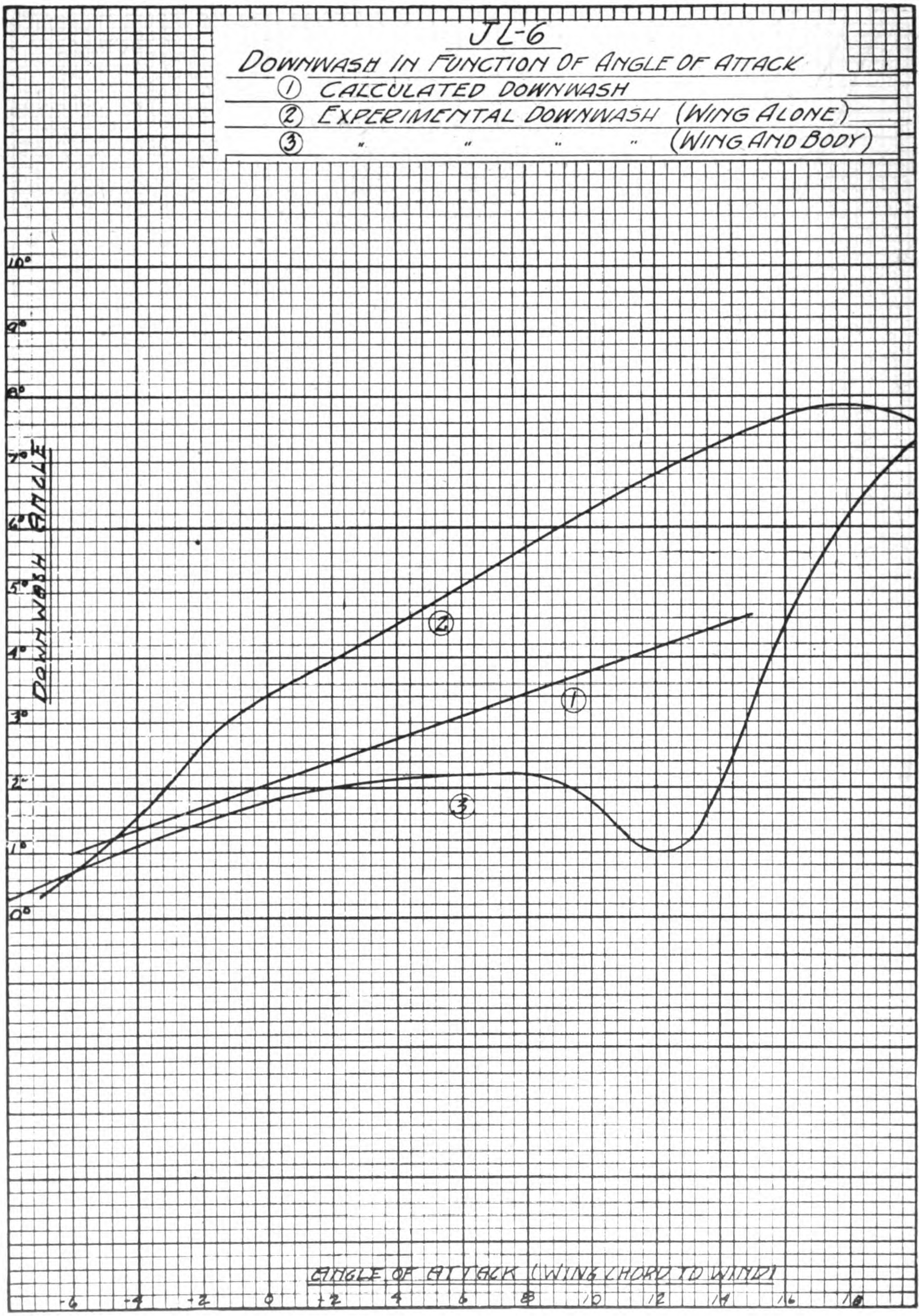

JL-6
DOWNWASH IN FUNCTION OF ANGLE OF ATTACK
① CALCULATED DOWNWASH
② EXPERIMENTAL DOWNWASH (WING ALONE)
③ " " " " (WING AND BODY)
DOWNWASH ANGLE
10°
9°
8°
7°
6°
5°
4°
3°
2°
1°
0°
ANGLE OF ATTACK (WING CHORD TO WIND)
-6
-4
-2
0
+2
4
6
8
10
12
14
16
18

FIG. 7.

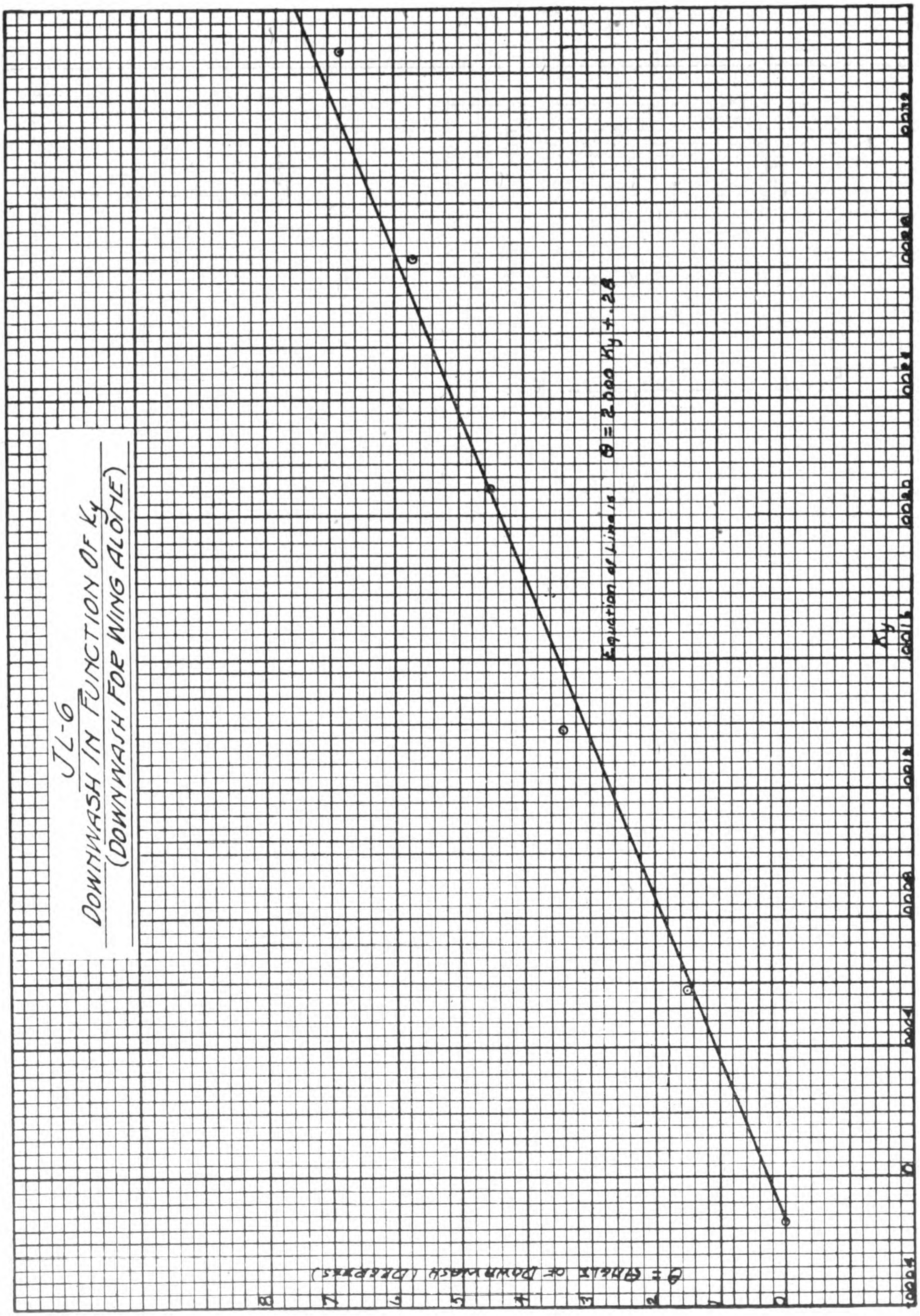

JL-6
DOWNWASH IN FUNCTION OF Ky
(DOWNWASH FOR WING ALONE)
Equation of Line is θ = 2.000 Ky + .28
Ky

FIG. 8.

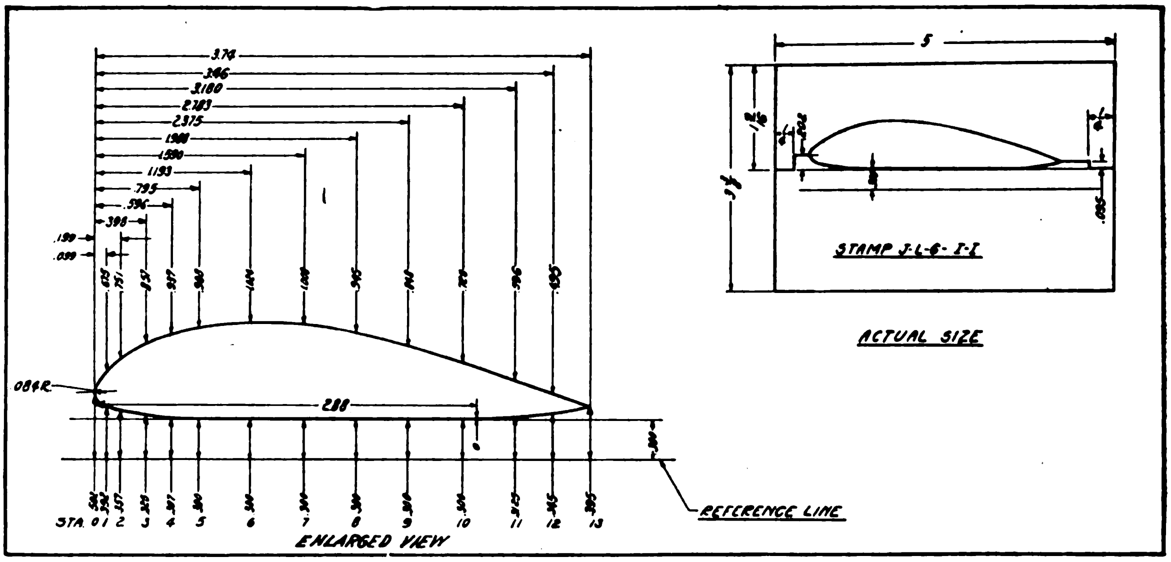


FIG. 9.—Template for aerofoil section I-I JL-6.

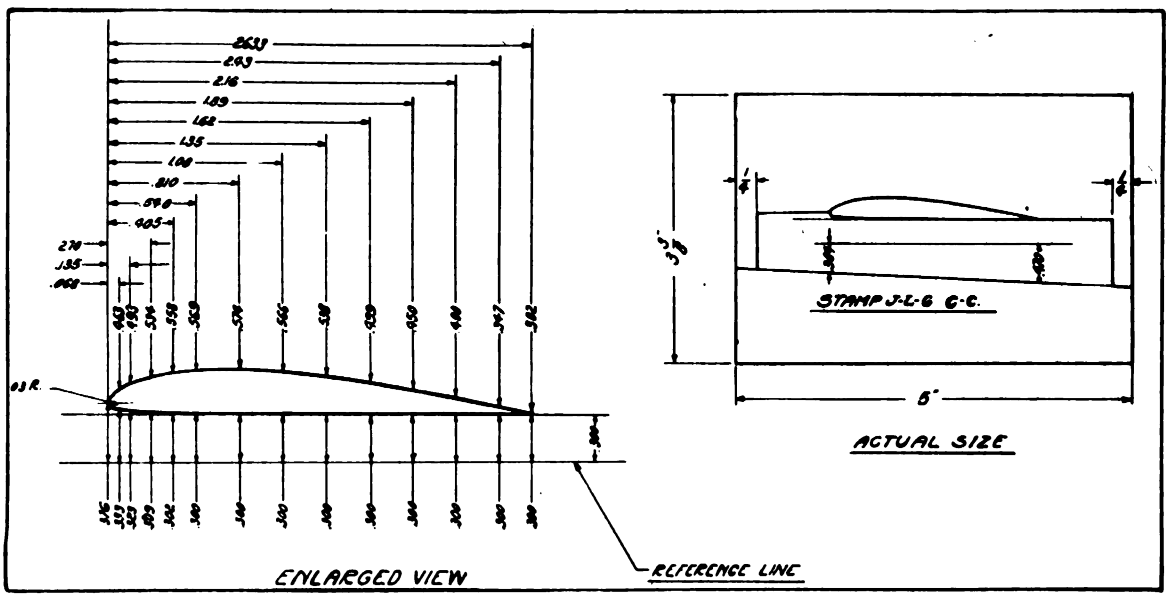


FIG. 10.—Template for aerofoil section C-C JL-6.

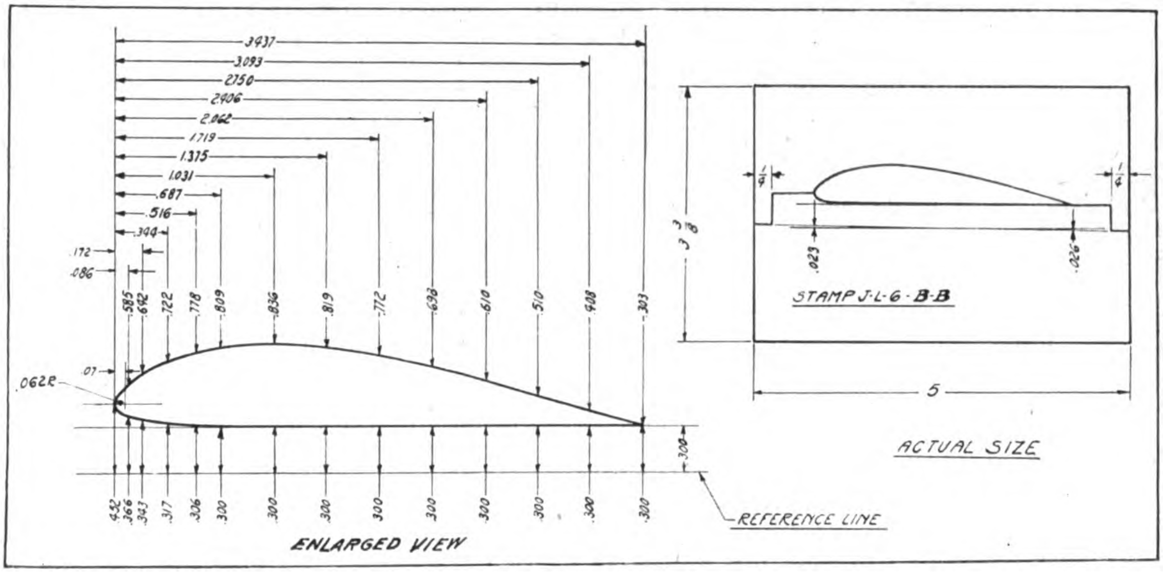


FIG. 11.—Template for aerofoil section B-B JL-6.

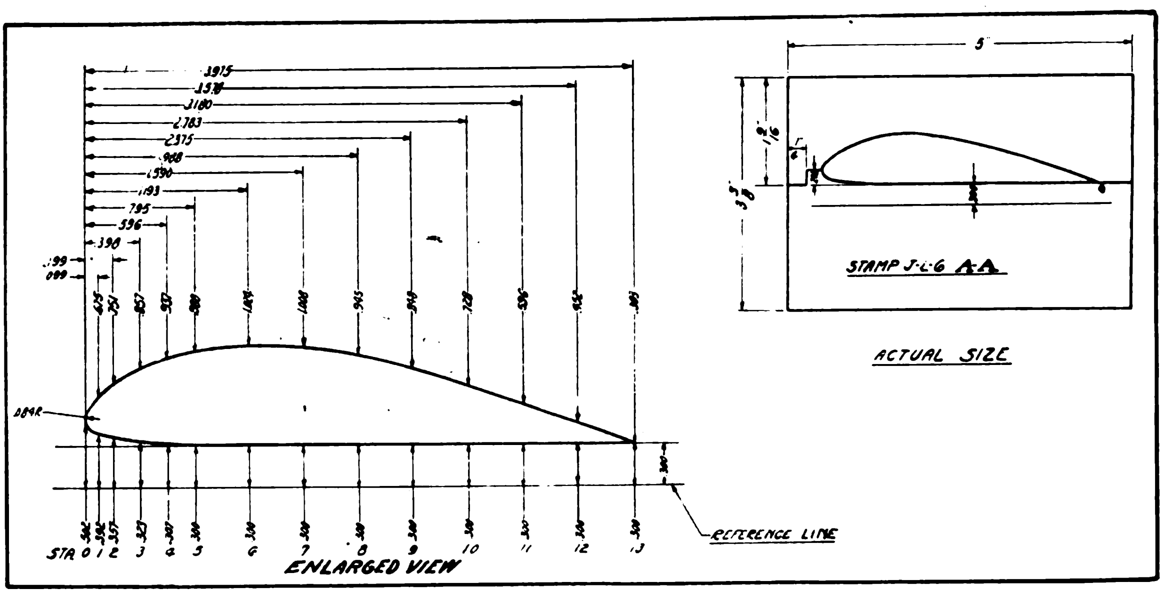


FIG. 12.—Template for aerofoil section A-A Junker JL-6.

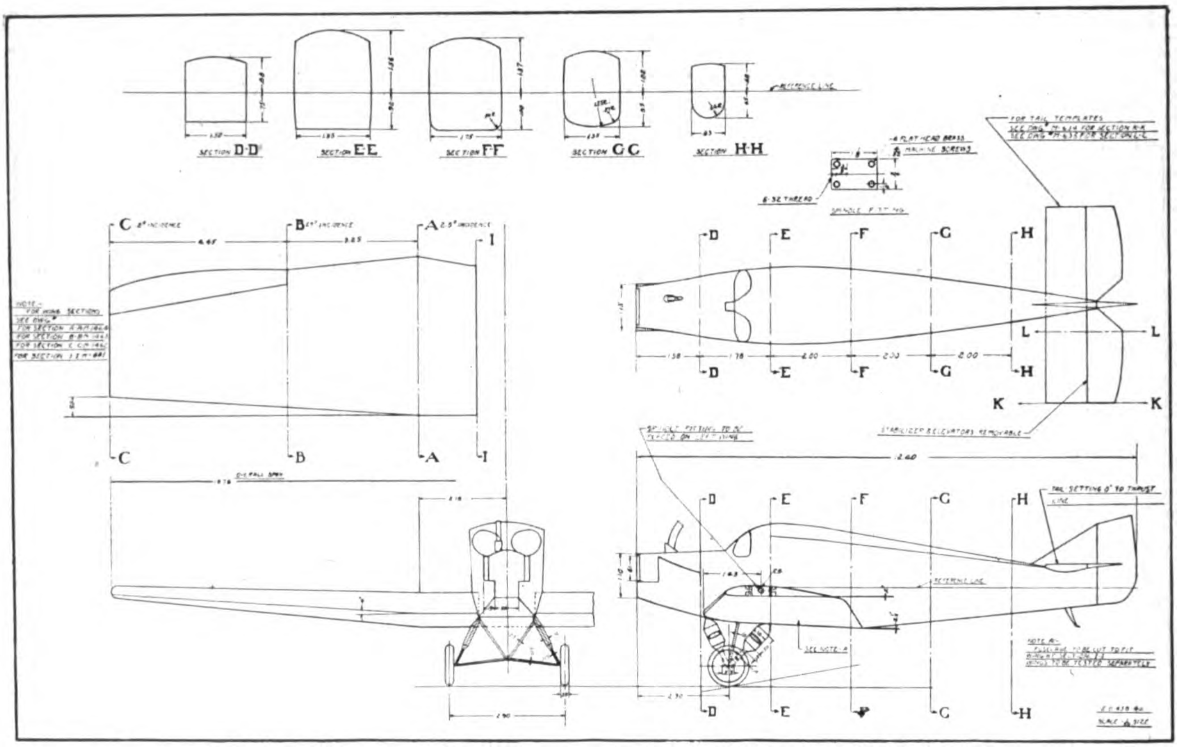


FIG. 13.

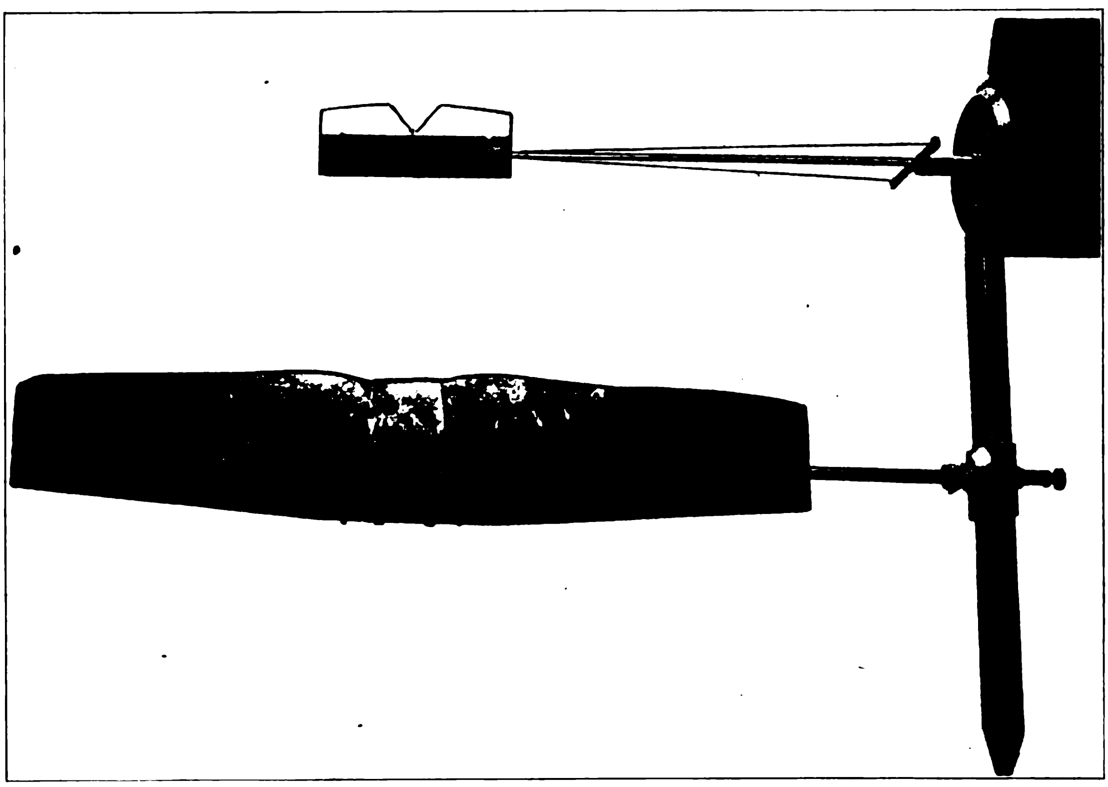


FIG. 14.

As lift is imparted to a wing by virtue of the downward momentum given to the air, the down wash should be zero for zero lift. The down-wash angle is seen to be a linear function of the lift coefficient, as has been found to be the case for other wings.

The wing alone shows no peculiarities, as has been before noted, but this experiment has brought out very clearly the fact that account must be taken of the body in the calculation of down wash.

the tail plane to the horizontal is 3.8° greater at point A than at point B. Then the angle of the wind stream to the horizontal must also be 3.8° greater at point A than at point B, or the angle of down wash is 3.8°. Similarly, the down wash for any point on curve (1) is the difference in angle of attack between that point and the point of equal moment on curve (2).

Curve (3) is down-wash angle plotted against angle of attack.

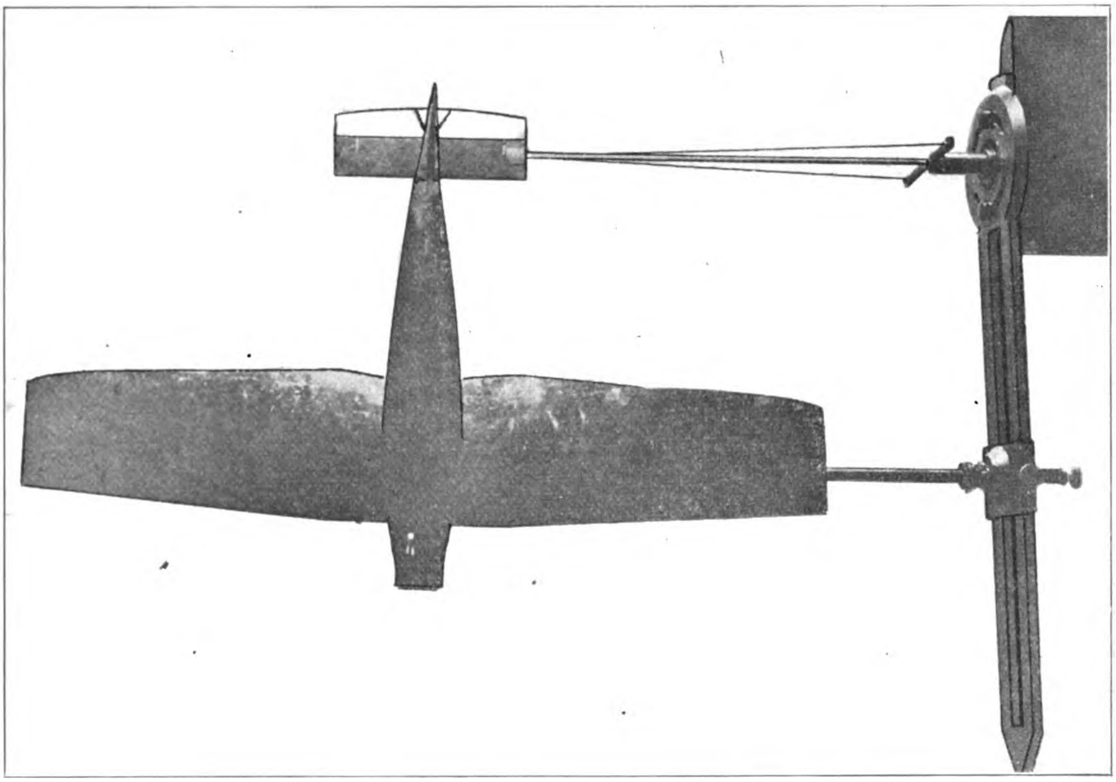


FIG. 15.

EXPLANATION OF CALCULATION OF DOWN-WASH ANGLE.

In Figure 6 the moments for the tail alone, curve (2), and for the effective tail, curve (1), are plotted against wing angle of attack. The moment for the effective tail is the difference between the moment for the complete model and the moment for the model without the tail plane. Curve (1), then, is the moment for the tail alone, but influenced by the presence of the wings and body.

With other conditions constant, the lift, and therefore the moment about the center of gravity for the tail plane, varies only with its angle of attack. In Figure 6, since the moment at point A for the effective tail is the same as at point B for the tail alone, the tail-plane angle of attack must be the same for these two points. But the angle of

TABLE 1.—*Junker L-6 monoplane (complete model).*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

i	L	D	L/D	M
−8	−0.176	0.0925	−1.90	....
−6	−.026	.0782	−.33	+0.121
−4	+.128	.0719	1.78	.133
−2	.269	.0733	3.67	.096
0	.417	.0787	5.29	.061
2	.576	.0880	6.54	.077
4	.731	.1015	7.20	.072
6	.880	.1204	7.31	.067
8	1.013	.1418	7.15	.048
10	1.146	.1664	6.88	.030
12	1.257	.1971	6.37	.013
14	1.439	.2125	6.76	.056
16	1.550	.2349	6.60	.200
18	1.554	.2723	5.70	.169
20	1.479	.3137	4.71	....

Tail plane 0° to thrust line.
Elevators 0° to thrust line.

TABLE 2.—*Junker L–6 monoplane (complete model).*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

i	L	D	L/D	M
−8	−0.179	0.0961	....	+0.2437
−6	−.032	.0821	....	.2725
−4	+.112	.0757	1.48	.2795
−2	.253	.0765	3.31	.2471
0	.402	.0803	5.01	.2177
+2	.564	.0901	6.26	.2056
4	.715	.1040	6.87	.1834
6	.861	.1214	7.09	.1765
8	1.000	.1429	7.00	.1605
10	1.131	.1682	6.73	.1427
12	1.254	.1988	6.30	.1100
14	1.409	.2184	6.44	.2688
16	1.539	.2337	6.58	.3001
18	1.534	.2720	5.64	.2716
20	1.478	.3128	4.72	.2309

Tail plane 0° to thrust line.
Elevators +5° to thrust line.

TABLE 3.—*Junker L–6 monoplane (complete model).*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

i	L	D	L/D	M
−8	−0.194	0.1022	....	+0.3113
−6	− .043	.0889	....	.3777
−4	+ .088	.0820	1.07	.4478
−2	.229	.0808	2.83	.4517
0	.377	.0842	4.48	.3926
+2	.534	.0919	5.80	.3767
4	.692	.1055	6.56	.3567
6	.846	.1228	6.89	.3332
8	.981	.1439	6.81	.3016
10	1.119	.1682	6.65	.2768
12	1.224	.1961	6.24	.2367
14	1.384	.2165	6.39	.2988
16	1.504	.2326	6.46	.4018
18	1.501	.2682	5.60	.3624
20	1.115	.3528	3.16	.0470

Tail plane 0° to thrust line.
Elevators +10° to thrust line.

TABLE 4.—*Junker L–6 monoplane (complete model).*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

i	L	D	L/D	M
−8	−0.203	0.1082	−1.87	+0.4264
−6	− .057	.0950	− .6	.4831
−4	+ .078	.0892	+ .87	.5700
−2	.209	.0876	2.49	.6209
0	.353	.0894	3.95	.5817
+2	.524	.0965	5.43	.5466
4	.674	.1082	6.23	.5177
6	.819	.1256	6.51	.4789
8	.973	.1458	6.55	.4211
10	1.100	.1690	6.51	.3925
12	1.205	.1973	6.11	.3386
14	1.383	.2167	6.39	.4988
16	1.558	.2316	6.72	.5220
18	1.500	.2693	5.57	.4188
20	1.205	.3532	3.41	.1904

Tail plane 0° to thrust line.
Elevators +15° to thrust line.

TABLE 5.—*Junker L–6 monoplane (complete model).*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

i	L	D	L/D	M
−6	+0.003	0.0752	0.04	−0.023
−4	.154	.0702	2.20	− .041
−2	.298	.0724	4.11	− .073
0	.447	.0784	5.70	− .084
+2	.608	.0889	6.84	− .082
4	.755	.1038	7.27	− .082
6	.906	.1233	6.60	− .089
8	1.041	.1454	7.16	− .090
10	1.174	.1724	6.80	− .086
12	1.289	.2032	6.34	− .115
14	1.453	.2228	6.52	− .002
16	1.568	.2400	6.54	+ .078
18	1.566	.2789	5.61	+ .043
20	1.508	....	....	....

Tail plane 0° to thrust line.
Elevators −5° to thrust line.

TABLE 6.—*Junker L–6 monoplane (complete model).*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

i	L	D	L/D	M
−8	−0.133	....	....	....
−6	+ .022	0.0720	0.30	−0.187
−4	.173	.0686	2.52	− .206
−2	.317	.0720	4.40	− .242
0	.471	.0785	6.00	− .245
+2	.628	.0895	7.01	− .236
4	.774	.1047	7.40	− .226
6	.928	.1250	7.42	− .226
8	1.062	.1481	7.16	− .225
10	1.195	.1757	6.80	− .220
12	1.296	.2053	6.31	− .222
14	1.464	.2266	6.46	− .084
16	1.591	.2445	6.50	− .039
18	1.579	.2842	5.55	− .072
20	1.521	....	....	....

Tail plane 0° to thrust line.
Elevators −10° to thrust line.

TABLE 7.—*Junker L–6 monoplane (wing alone):*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size. (Area=68.76 sq. in.)

i	Ky	Kx	L/D	C. P.	$M_{coeff.}$
−8	−0.00014	0.000084	1.66	....	−0.000188
−6	+.00023	.000071	3.2	1.300	−.000286
−4	.00058	.000073	8.0	.660	−.000380
−2	.00095	.000082	11.6	.513	−.000481
0	.00138	.000101	13.5	.443	−.000607
2	.00177	.000130	13.6	.408	−.000723
4	.00213	.000164	13.0	.387	−.000827
6	.00250	.000203	12.3	.374	−.000942
8	.00283	.000248	11.4	.365	−.00103
10	.00315	.000296	10.6	.360	−.00113
12	.00347	.000351	9.9	.354	−.00124
14	.00371	.000401	9.3	.352	−.00130
16	.00377	.000462	8.2	.350	−.00130
18	.00372	.000545	6.8	.355	−.00131
20	.00349	.000641	5.4	.361	−.00126

Table 8.—*Junker L-6 monoplane (complete minus elevator and stabilizer).*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

i	L	D	L/D	M
−8	−0.080	0.0714	....	−0.507
−6	+.076	.0630	1.21	−.456
−4	.215	.0629	3.42	−.384
−2	.345	.0678	5.08	−.303
0	.490	.0758	6.46	−.212
2	.638	.0871	7.33	−.142
4	.783	.1032	7.56	−.059
6	.922	.1230	7.50	+.011
8	1.054	.1444	7.30	.086
10	1.167	.1705	6.84	.163
12	1.270	.1993	6.36	.222
14	1.498	.2079	7.20	.362
16	1.562	.2345	6.66	.416
18	1.539	.2718	5.65	.418
20	1.485	.3128	4.74	.380

Table 9.—*Junker L-6 monoplane (elevator and stabilizer alone).*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

i	L	D	L/D	M
−8	−0.065	0.0132	....	+0.571
−6	−.056	.0102	....	+.492
−4	−.048	.0076	....	+.419
−2	−.035	.0057	....	+.311
0	−.023	.0047	....	+.205
+2	−.011	.0045	....	+.090
4	+.002	.0053	0.38	−.011
6	.015	.0070	2.14	−.128
8	.030	.0098	3.06	−.263
10	.041	.0135	3.04	−.364
12	.049	.0171	2.87	−.444
14	.056	.0214	2.62	−.515
16	.062	.0261	2.37	−.583
18	.066	.0297	2.22	−.625
20	.068	.0334	2.03	−.656

Table 10.—*Junker L-6 monoplane (complete minus elevators).*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

i	L	D	L/D	M
−8	−0.173	0.0921	....	....
−6	−.023	.0773	....	−0.120
−4	.125	.0740	1.69	−.050
−2	.269	.0753	3.57	+.006
0	.411	.0804	5.11	.038
+2	.568	.0898	6.32	.060
4	.728	.1036	7.04	.078
6	.877	.1214	7.22	.099
8	1.020	.1430	7.12	.116
10	1.154	.1667	6.93	.132
12	1.276	.1960	6.51	.141
14	1.450	.2163	6.70	.176
16	1.576	.2362	6.67	.331
18	1.582	.2705	6.85	.334
20	1.534	.3120	4.91	.306

Table 11.—*Junker L-6 monoplane.*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

EXPERIMENTAL DOWN WASH.

Wing incidence	Ky	Down wash due to wings	Down wash due to wings and body
°		°	°
−8	−0.00014	0.0	0.3
−4	+.00058	1.5	1.1
0	.00138	3.4	1.8
+4	.00213	4.5	2.1
8	.00283	5.7	2.2
12	.00347	6.8	1.0
16	.00377	7.7	4.5
20	.00349	7.6	7.3

Table 12.—*Junker L-6 monoplane.*

Authority: Aerodynamical Laboratory, M. I. T., April, 1921.
Velocity: 30 miles per hour.
Model: 1/30 size.

MOMENTS ABOUT C. G. FOR CALCULATED DOWN WASH.

i	(1) M for complete model	(2) M for model minus tail	(3) M for effective tail	(4) M for tail alone	(5) Angle of down wash
					°
−8	....	−0.507	....	0.571	....
−6	0.121	−.456	0.577	.492	1.0
−4	.133	−.384	.517	.419	
−2	.096	−.303	.399	.311	1.7
0	.061	−.212	.273	.205	
+2	.077	−.142	.219	.090	2.4
4	.072	−.059	.131	−.011	
6	.067	+.011	.078	−.128	3.1
8	.048	.086	−.038	−.263	
10	.030	.163	−.133	−.364	3.8
12	.013	.222	−.209	−.444	
14	.056	.362	.306	−.515	4.6
16	.200	.416	.216	−.583	....
18	.169	.418	.249	−.625	....
20	....	.380	....	−.656	....

(1) From Table 1.
(2) From Table 8.
(3) =(1)—(2).
(4) From Table 9.
(5) From Figure 6.

Table 13.—*Comparison of aerofoils.*

Aerofoil.	U. S. A.-27.	Junker.
Maximum Ky (landing)	0.00363	0.00377
Minimum Kx	.00008	.00007
Maximum L/D (cruising)	16.1	13.7
High-speed pursuit, L/D at $\frac{\text{Ky (max.)}}{9}$	4.6	5.1
High-speed reconnaissance, L/D at $\frac{\text{Ky (max.)}}{6.25}$	7.0	8.1
High-speed bomber, L/D at $\frac{\text{Ky (max.)}}{4}$	11.7	11.5
Speed range $\frac{\sqrt{\text{Ky (max.)}}}{\sqrt{\text{Kx (min.)}}}$	1.41	1.49
Ceiling and climb. constant loading $\frac{\text{Ky } 3/2}{\text{Ky}}$ (max. value)	.665	.61
Ceiling and climb. constant landing speed $\frac{\sqrt{\frac{\text{Ky (max.)}}{\text{Ky}}}}{\text{L/D}}$ (min. value)	.0908	.1006
Most forward position of center of pressure	27.4	35.2
C. P. travel in per cent of chord between most forward position of C. P. and position at angle of $\frac{\text{Ky max.}}{6.25}$	39.6	28.8
Moment coefficient with respect to L. E. for angle of zero lift	....	.00028
Spar depths in per cent of chord:		
10 per cent from leading edge	9.17	[1] 13.50
15 per cent from leading edge	10.40	[1] 15.75
60 per cent from leading edge	9.27	[1] 13.75
70 per cent from leading edge	7.90	[1] 9.10
Authority	M. I. T.	M. I. T.
Date test run	November, 1920.	April, 1921
Aspect ratio	6	[2] 5.5
Velocity, miles per hour	30	30

[1] At root section.
[2] Chord = area/span.

File D 52.411/32 *McCOOK FIELD REPORT, SERIAL No. 1901*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV September 1, 1922 No. 368

TESTS OF BACK-SUCTION AND AIR-BLEED TYPE MIXTURE CONTROLS IN FLIGHT

(POWER PLANT SECTION REPORT)

▽

Prepared by C. F. Taylor
Engineering Division, Air Service
McCook Field, Dayton, Ohio
March 23, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

TESTS OF BACK-SUCTION AND AIR-BLEED TYPE MIXTURE CONTROLS IN FLIGHT.

OBJECT OF TESTS.

The object of these tests was to determine the effect on engine performance of several types of back-suction and one type of air-bleed carburetor mixture controls under actual flight conditions. From the results of these tests it was hoped that more satisfactory forms of control could be developed.

SUMMARY OF RESULTS.

All the "back-suction" controls tested proved to be sensitive and difficult to adjust. The uncertainty of readings obtained under flight conditions was apparent throughout the tests.

The following is a summary of the results obtained with the individual carburetors and controls:

TYPE "A" CONTROL.

Standard type 85–A back-suction control on Zenith U. S. 52 carburetor for Liberty "12" engine. The particular control tested appeared to be effective to an altitude of 19,000 feet. In service use, however, it has been found that different carburetors of the U. S. 52 type vary greatly, and many of the controls are not effective to such a high altitude.

TYPE "B" CONTROL.

Special back-suction control consisting of one valve piped to both Zenith U. S. 52 carburetors on a Liberty "12" engine. The flight tests of this control showed conclusively that at a certain point in its range the functioning of the carburetor was seriously interfered with, and the mixture could not be made leaner. It is believed that the flow through the compensator jet was reversed at this point.

TYPE "C" CONTROL.

Standard arrangement on Stromberg NA–D6 carburetor mounted on Hispano-Suiza model "H" engine. This control is only effective to an altitude between 12,000 and 16,000 feet, due to the excessively rich jet setting which is used on this carburetor.

TYPE "D" CONTROL.

Special two-way back-suction valve on Stromberg NA–D6 carburetor mounted on Hispano-Suiza model "H" engine. This control was effective to an altitude of somewhat less than 16,000 feet. Its action was quite similar to that of the type "C" control.

TYPE "E" CONTROL.

This was a Stromberg NA–D6 modified carburetor with standard control. The control is the same as type "C," but the main jet of the carburetor is reduced from No. 32 drill size to No. 35, thus increasing the actual effectiveness of the control. On test this appeared to be effective to something over 20,000 feet.

TYPE "F" CONTROL.

Standard air-bleed type control on old-style Packard double-venturi carburetor. Flight test indicated that control was effective to 20,000 feet. Since this is the only flight test conducted by the Engineering Division on this type of control, the results are open to question.

TYPE "G" CONTROL.

Air-bleed control on Packard double-venturi carburetor with special valve. Preliminary runs on the dynamometer indicated that this had no advantage over the standard Packard control, and it was therefore never flight tested.

TYPE "H" CONTROL.

Back-suction control with two-way valve on Packard double-venturi carburetor. This control proved to be entirely too powerful and too sensitive for practical use. It also interfered with the action of the compensator.

CONCLUSIONS.

From the results obtained the following conclusions are indicated, but it is believed that in order to check them with scientific accuracy the controls should be tested in a carburetor metering box equipped for simulating altitude conditions.

The back-suction type of control is too sensitive, i. e., at certain points a small change in the position of the control lever causes the engine to stop or slow down very suddenly.

By a good pilot, considerable saving in fuel at altitudes can be obtained, even with the back-suction type.

Sufficient depression can be obtained from above the venturi, in normal carburetors, to give adequate control of a single-venturi nozzle up to 20,000 feet.

Sufficient depression can be obtained from the throat of the main venturi to give adequate control of a double-venturi nozzle up to 20,000 feet provided the jet setting gives reasonably low fuel consumption at sea level.

It is not necessary for a control to be able to stop an engine, running wide open on the ground, in order to be sufficiently effective at 20,000 feet. Beyond this, no definite relation between performance of control on ground and at altitude has been established.

Insufficient experience with the air-bleed type of control has been obtained to reach any very definite conclusions as to its merits, but it is believed that the change in carburetor metering characteristics which is caused by a

change in the relative size of jet and air bleed constitutes a serious objection to this type of control, and its further development is not recommended.

In general, the back-suction and air-bleed types of mixture control are considered unsatisfactory, and the development of more promising types is recommended.

REFERENCES.

ENGINEERING DIVISION REPORTS.

1. Standard engine report of 12-cylinder Liberty motor, Serial No. 754, pages 21–23, inclusive.

2. Standard engine report of 8-cylinder Hispano-Suiza engine (300 horsepower), Serial No. 796, pages 21–23, inclusive.

3. Standard engine report on Packard model 1A–744 engine, Serial No. 1187, pages, 23, 24, and 26.

4. Instructions for installing 85–A mixture control in Zenith U. S. 52 carburetors, Serial No. 1385 (A. S. Information Circular, vol. 2, No. 175).

5. Report on tests to improve the Stromberg NA–D6 carburetor on the 300-horsepower Hispano-Suiza engine, Serial No. 1717 (A. S. Information Circular, vol. 4, No. 309).

6. The control of carburetor metering characteristics by the supplementary addition of air, Serial No. 1670 (A. S. Information Circular ,vol. 3, No. 292).

7. Report on the auxiliary air-port type altitude control as applied to Zenith carburetor, model U. S. 52, Serial No. 1811.

8. Instructions to pilots for the operation of mixture controls, Serial No. 1609 (A. S. Information Circular, vol. 3, No. 257).

DESCRIPTION.

For purposes of this report, the various types of altitude or mixture control have been designated alphabetically from "A" to "H," inclusive, and will be referred to by these letters throughout the report.

The Zenith U. S. 52 carburetor with type "A" control is manufactured by the Zenith Carburetor Co., of Detroit, Mich. The Stromberg NA–D6 carburetor with type "C" control and type "E" control is manufactured by the Stromberg Motor Devices Co., of Chicago, Ill. The Packard double-venturi carburetor with type "F" control was manufactured by the Packard Motor Car Co., of Detroit, Mich. All the other controls covered by this report were made and adapted to the corresponding carburetors by the shops of the Engineering Division.

Type "A" control was the standard 85–A control which is used on all up-to-date model U. S. 52 Zenith carburetors on the standard Liberty "12" cylinder engine. A description of this control may be found in reference No. 1. It is of the "back-suction" type, in which the mixture is made lean by opening a passage from above the venturi tubes to the float chamber and thus reducing the effective head on the jets. The float chamber is normally under air intake pressure by virtue of a connection between it and the top of the compensator wells, each compensator well being connected to the air space behind the venturis by a No. 17 drill hole. The flow of air from behind the venturis into the float chamber is restricted by a collar on the accelerating well tube. This method of restriction is believed to be at fault, since the accelerating well itself is rough drilled and the diameter varies between different carburetors. Small variations in the diameter of the accelerating well and the diameter of the collar on the accelerating tube make comparatively large variations in the effective areas of the restricting passage. It has been found in service that the effectiveness of controls will vary widely between a number of carburetors of this type.

Type "B" control was an experimental design supposed to correct the faults of type "A." Referring to Figure 1, it may be seen that this control consisted of a number of modifications on the standard U. S. 52 carburetor. On each of the two carburetors of a Liberty engine, a one-fourth inch copper "vacuum pipe" was led from the throat of each venturi to a point near the top of the float chamber. It was believed that the location of the end of these pipes at the throat of the venturi would make available a much higher suction than with the standard control and, therefore, a much more powerful control. Where the tube entered the float chamber a small drilled plug was provided to act as a restriction. The restriction hole at this point was No. 56 drill size in the first installation. The communication between the compensator well and the float chamber was cut off by means of a short section of brass tubing which was pressed into the upper end of the compensator well. Atmospheric pressure was communicated to the float chambers by means of three-eighths inch copper tubing. A section of this tubing was connected at each end to the cover of each float chamber. At the center of this same piece of tubing was a tee from which tubing of similar diameter led down to the control valve which was mounted on the side of the crank case of the engine. Another piece of tubing led from the control valve to the atmosphere, outside of the cowling of the engine compartment. The valve consisted of a flat circular seat with a hole which registered with the tube leading to the carburetors. A disk-shaped piece of brass formed the moving member of the valve. The edge of this disk was cut away as shown in Figure 1 so that in the full rich position the hole was fully uncovered and by moving the valve to the lean position the hole was gradually covered up. In the full lean position the hole was entirely covered. The space above the disk was closed by a cover through which the operating shaft of the valve extended to a lever connected to the pilot's control. The disk was held against its seat by a small spring. The atmospheric pipe was connected through the cover of the valve.

From the illustration and description the action of this valve is apparent. In the full rich position the valve is wide open, which allows atmospheric pressure to be communicated to the float chambers. The piping is sufficiently large, so that air drawn off by the suction pipes through the No. 56 restrictions was made up by air through the valve and piping without undue reduction below atmospheric pressure on the float chamber. As the valve was turned toward the lean position the atmospheric passage was progressively made smaller and the vacuum passages had a correspondingly increasing effect, until in the full lean position the float chamber was exposed to the full suction from the throat of the venturi and the flow of gasoline through the jets was thus greatly reduced or perhaps cut off entirely.

It was believed that this type of valve would have the following advantages over the 85–A control:

(a) Effective to greater altitude.

(b) Uniform between different carbureters, since the size of the atmospheric bleed hole and the vacuum holes could be held to close limits.

(c) Uniform in action between the two carburetors on the same engine, since both float chambers were bound to have the same pressure, due to the arrangement of piping.

(d) Smoother in action, due to the peculiar shape of the control valve disk.

Type "C" control was the standard control supplied on the Stromberg NA–D6 carburetor, which is described in reference No. 2. In addition, a sectional drawing of this control is shown in Figure 2.

Referring to the drawing, it will be seen that this is a "back-suction" control in which the float chamber receives atmospheric pressure through a restricted orifice communicating with the air intake of the carburetor just below the venturis. Suction is applied to the float chamber through a passage from the space back of the venturis. This space is under depression, due to four small holes drilled through each venturi at a point somewhat above the throat. The suction transmitted to the float chamber is controlled by a cylindrical valve, as shown. The capacity of the suction passage is supposed to be sufficiently large to overcome the effect of the restricted atmospheric vent in the full lean position.

Type "D" control, shown in Figure 3, is similar in principle to the type "C" control, in that it derives its suction from the space behind the venturis. The control valve, however, is a two-way valve with a flat disk, whose edges are notched in a manner exactly similar to the valve used in the type "B" control on the Zenith carburetor (see fig. 1). One port of the valve is connected to the space behind the venturis, while the other port is connected by copper tubing to the air intake of the carburetor. The space below the rotatable disk of the valve is connected to the top of the float chamber. In the full lean position the suction passage is wide open and the atmospheric passage closed. In moving from one position to the other the shape of the valve disk is such that one passage is opened gradually while the other is closed proportionately. It will be seen from this that the pressure in the float chamber is under the control of the pilot at all times between the limits of the pressure in the air intake and the suction behind the venturi. The normal atmospheric vent to the float chamber is plugged.

The object sought in the design of the above control was to provide a valve which would be extremely gradual in its operation and, therefore, be easy of adjustment. A further advantage is that there is no flow of air through the float chamber, and that the control has a wider range than type "C," due to the absence of a constant atmospheric vent to the float chamber.

Type "E" control was the standard NA–D6 arrangement used with a modified NA–D6 carburetor (see reference No. 5). In the modified carburetor the main jet is considerably smaller than in the standard carburetor, therefore a given setting of the control will give a leaner mixture in the case of the modified carburetor. It was therefore believed that the type "E" control would be effective to a greater altitude than the type "C."

The type "F" control was the standard control supplied on the Packard double-venturi carburetor for the model 1A–744 eight-cylinder engine. This control is described in reference No. 3, and Figure 4 also shows the standard control valve. It consists of a cylindrical sleeve, the inside of which is in communication with the atmosphere through two vertical holes drilled in the carburetor casting. In the full rich position this valve communicates with the main fuel passage by means of an extremely small hole, the function of which is to prevent syphoning of the gasoline from the emulsion well to the venturi nozzle. In moving the control valve toward the lean position a port in the valve comes into registry with the main fuel passage, thus allowing air to be drawn into the passage by virtue of the suction at the nozzle. The float chamber is vented to the atmosphere by a fixed orifice.

The theory of this control is that as the main fuel passage becomes vented to the atmosphere the nozzle will draw more air and less gasoline. It should be noted that this is in effect a variable air bleed, and from previous experience with carburetors of the air-bleed type such as the Stromberg it has been found that the relation of the air-bleed size to the main jet size has a marked effect on the metering characteristics of the carburetor. It is therefore to be expected that with this type of control the characteristic metering curve of the carburetor will change with different settings of the control valve.

Type "G" control, shown in Figure 4, was a modification of type "F." The cover of the float chamber was replaced by a disk valve very similar to the two-way valve used on the type "D" control except that the disk was cut away under the atmospheric port so that the space within the valve was always under atmospheric pressure. The other port of the valve was connected by a copper pipe to the top of the emulsion well. It was belived that the suction at the nozzle would draw air through this pipe in the same way that it would draw air in the standard type "F" control valve.

The advantages of this control over the standard Packard control were supposed to be as follows:

(a) Control much more powerful, since all passages for the atmospheric air were much larger.

(b) Gradual operation, due to shape of valve disk.

This control is still open to the objection that the metering characteristics of the carburetor will probably change with different positions of the valve.

Type "H" control is the back-suction, two-way type applied to the Packard double-venturi carburetor on the model 1A–744 engine. It is similar in principle to the type "D" control on the NA–D6 carburetor. The details are shown in Figure 5.

Referring to Figure 5, sections A–A and B–B, it will be seen that the standard cylindrical control valve was withdrawn from its passage. Hollow plugs, vented to the air intake by copper piping, were placed in either end of this passage to supply air to the compensator wells and to provide the small atmospheric vent to the main fuel passage necessary to obviate syphoning. Between the two plugs remained a cylindrical passage communicating by two vertical drilled holes to the bottom of the carburetor. These holes are normally vented to the atmosphere, but in the case of the control in question small brass pipes were added which curved around and terminated in an

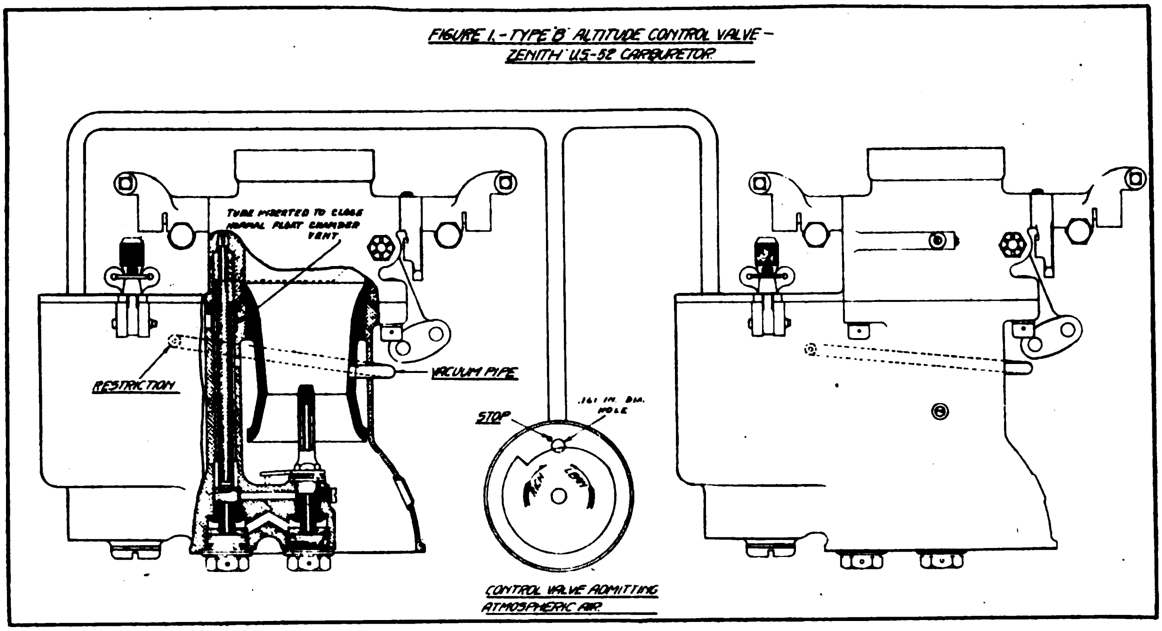


Fig. 1.—Type "B" altitude control valve—Zenith U. S.-52 carburetor.

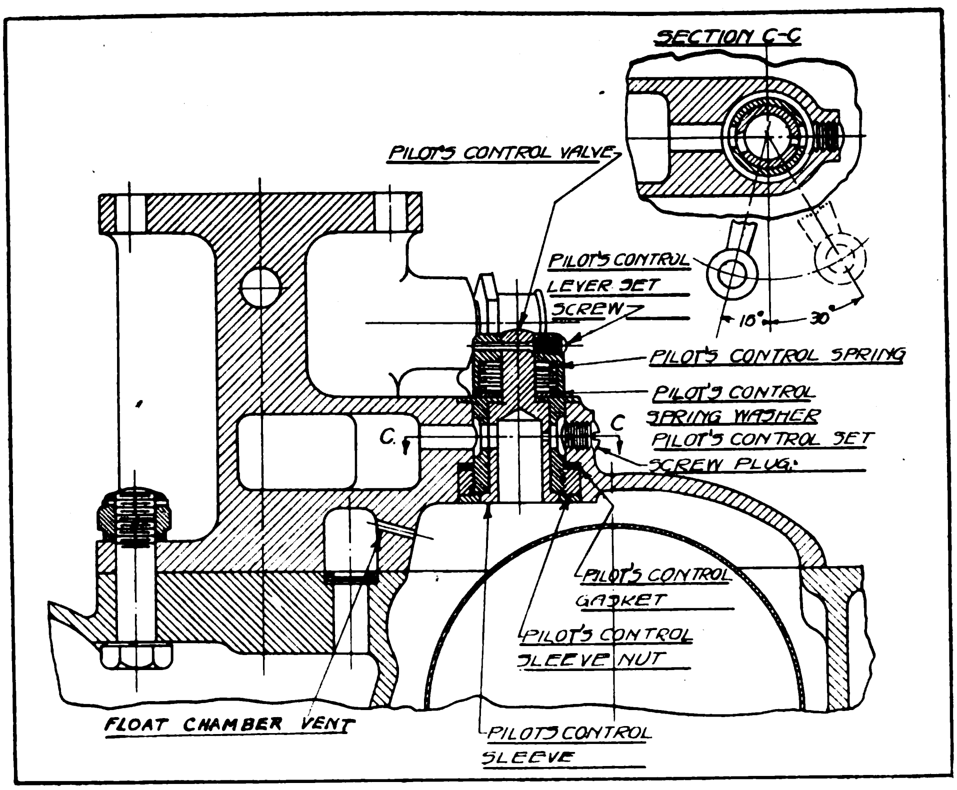


Fig. 2.—Type "C" Standard altitude control valve on Stromberg NA-D6 carburetor.

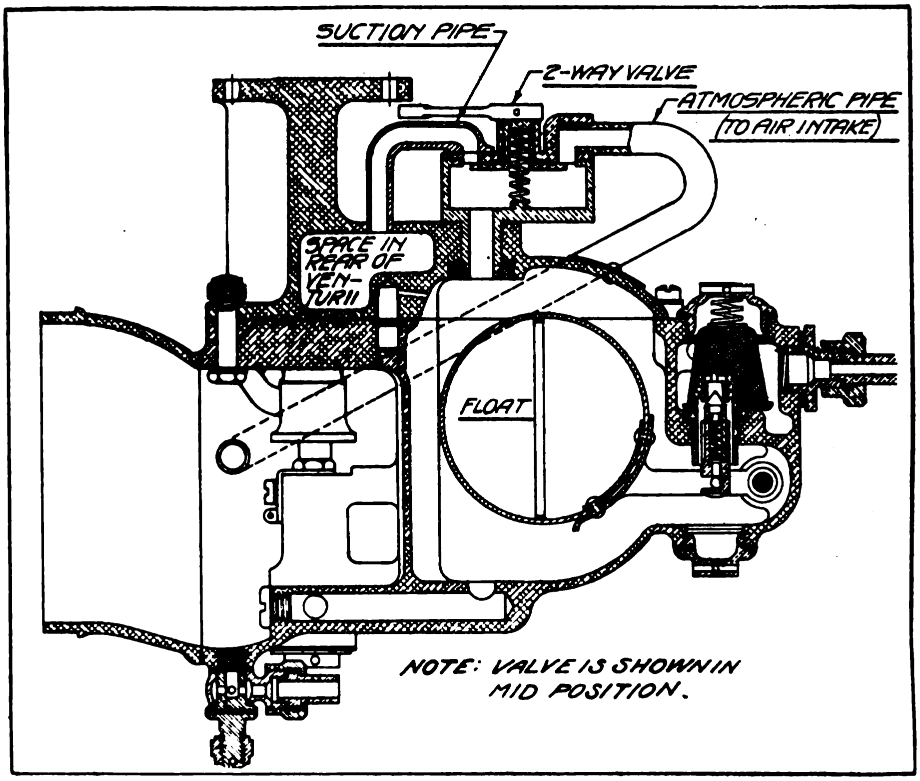


FIG. 3. Type "D" control applied to NA-D6 Stromberg carburetor.

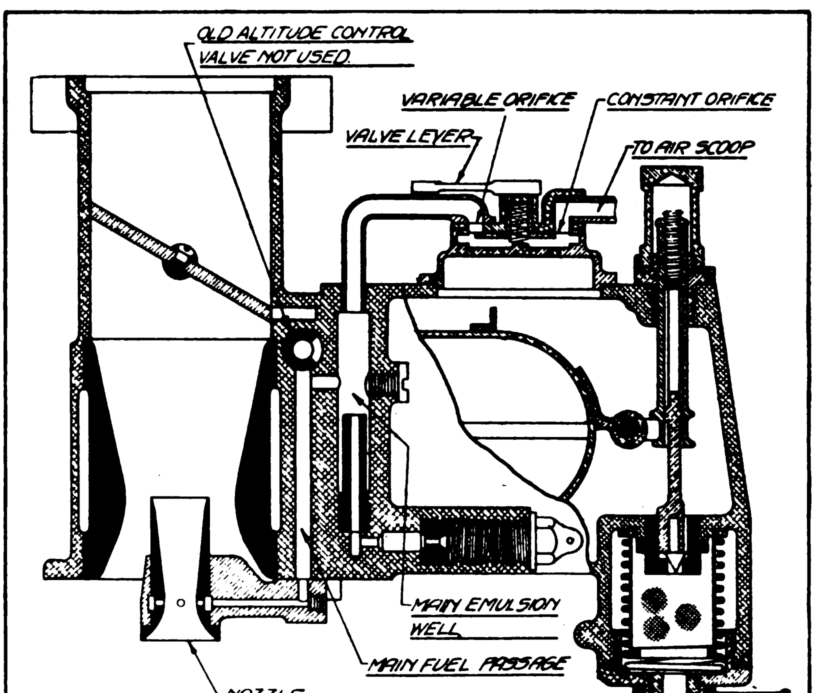


FIG. 4.—Type "G" control fitted to Packard carburetor on Packard Model 1A-744 Aviation engine.

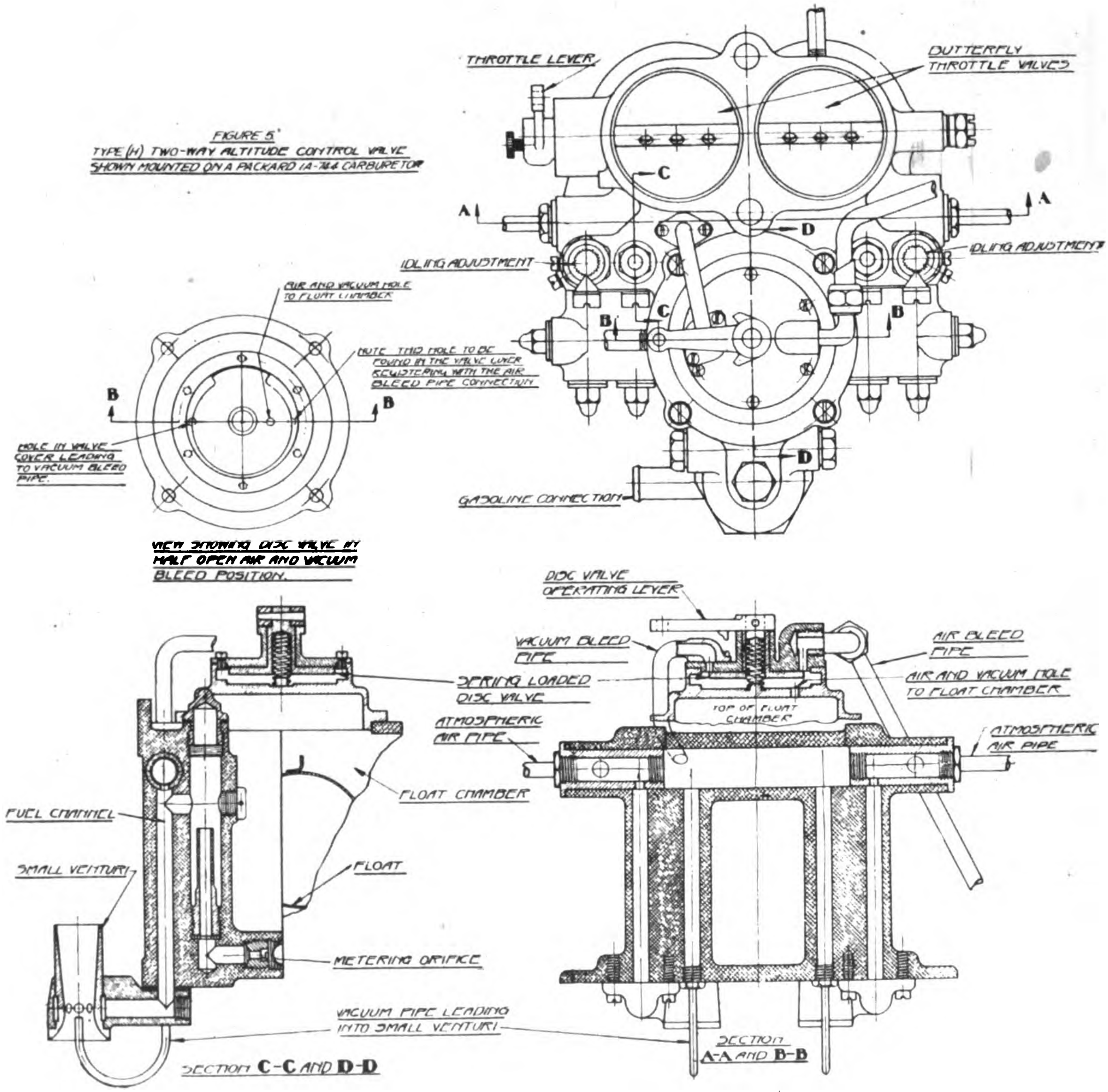


Fig. 5.—Type "H" two-way altitude control valve shown mounted on Packard 1A-744 carburetor.

open end at the center of each venturi nozzle. The horizontal cylindrical passage and the two vertical passages were, therefore, under constant suction transmitted to them by the small brass pipes communicating with the nozzles. The two-way control valve derived its suction from the horizontal cylindrical passage and its atmospheric pressure from a copper pipe leading down the side of the air intake. The valve disk was arranged for gradual opening as in the case of the valve disks previously described. The normal vent to the float chamber was plugged. In the full rich position the vacuum passage was entirely closed and the atmospheric passage wide open. This communicated atmospheric pressure to the valve chamber which was connected to the top of the float chamber through a hole in the bottom of the valve, shown in section B-B of the drawing. In the full lean position the opposite was the case, the atmosphere passage being closed and the vacuum passage being open. Sections C-C and D-D of Figure 5 show how the plug at either end of the horizontal passage communicated through a small hole with the main jet passage. Another view of Figure 5 shows the valve in mid-position with both the vacuum and atmospheric passages one-half open.

This design was made in an attempt to investigate the difference between the air-bleed and back-suction type of control on the same carburetor. It was designed as a very powerful control, as is shown by the fact that the suction was derived from the center of the venturi nozzle. With this suction fully applied to the float chamber and the atmospheric vent cut off, the flow of fuel through the nozzle would, in all probability, cease entirely.

METHOD OF TEST.

Each type of control was given a preliminary laboratory test to determine the action of the control, in various positions, on an engine running on the dynamometer. In each case the control was properly installed and the engine run at normal speed, full throttle, with the control valve in the full rich position. During this run readings of the revolutions per minute, brake load, float chamber vacuum, and fuel consumption were taken. With the engine still running, the control was shifted to the "best" position. The "best" position is defined as the leanest setting of the control which is possible without reducing the speed or power output of the engine. When this setting had been made, another run was conducted taking the same readings as before. The control was then shifted to the full lean position, and if the engine would still run the same readings were again taken.

In addition to the readings taken, these dynamometer runs served to show whether or not the engine was in good condition and gave a rough idea of the power of the control. The least powerful controls would cause very little drop in speed or brake load of the engine. Others caused a marked drop in speed and power, while still others would stop the engine entirely.

After the dynamometer test of each control it was installed on an engine mounted in an airplane and flight tested. Flight tests were designed to give the following information:

(*a*) Position of the lever for best setting at all altitudes from ground level to the service ceiling of the airplane,

(*b*) Action of the engine at several altitudes with the control set in the full rich, best, and full lean positions, respectively.

Most of the flight tests consisted of a climb at full throttle to service ceiling of the airplane, keeping the control lever set in the "best" position; that is, the leanest position which could be obtained without reducing the engine revolutions per minute. Readings were taken at intervals of 2,000 feet altitude of: Time after leaving the ground, engine revolutions per minute, position of the control lever, air speed of the airplane, and atmospheric temperature. In a few cases the flow of gasoline to the carburetor was taken by means of a Schroeder flowmeter and readings of the air temperature at the entrance to the carburetor "air scoop" were also taken on some of the tests. After climbing to service ceiling a level flight was made at full throttle with the control set successively at the best, full rich, and full lean positions. Under each of these conditions readings of the engine revolutions per minute, position of the control lever, and air speed were taken. Where possible, similar level flights were repeated at several suitable altitudes below service ceiling. For every test the lever in the cockpit which was connected to the altitude control valve was provided with a sector graduated in even divisions, and the position of the lever was indicated by the number of the division adjacent to it.

Many of the flight tests were incomplete due to various interferences such as unfavorable atmospheric conditions, trouble with mechanical equipment, etc. The extent of each test on any particular control and the results obtained may be determined by referring to Tables 1 to 13, inclusive.

ANALYSIS OF RESULTS.

In considering the results of the flight tests it should be remembered that the conditions under which they were made are not conducive to accurate results. For instance, the engine revolutions per minute is indicated by a tachometer which can not be read closer than 10 revolutions per minute. Furthermore, the engine speed under a given set of conditions will vary considerably with the attitude of the airplane, and although the pilot endeavored to hold the plane exactly horizontal during the level flights, this could not be done with absolute accuracy. Variations of 20 revolutions per minute may be expected due to this source of error. Another important source of error is the fact that there is no absolutely definite indication as to when the mixture control is set in the "best" position, due to the absence of an accurate method of observing the engine speed and to the fact that most of the controls were rather sudden in their action. Errors in setting the control lever, as great as 20 per cent of the lever travel, are probably present in most of the flight tests. These considerations should be borne in mind when analyzing the results obtained in the flight tests, and tendencies should be considered, rather than absolute values.

The results obtained in the dynamometer tests are considerably more accurate since the engine speed was taken by a positive counter, and comparatively accurate instruments for measuring torque and fuel consumption were used.

TYPE "A" CONTROL.

Referring to Table 1, it will be noted that the type "A" or Standard Zenith control effects a considerable reduction in fuel consumption over the full rich position when set in the "best" position. In the full lean position the engine speed was reduced approximately 400 revolutions per minute under dynamometer conditions and the running was irregular. Table 2 shows that the control was sufficiently powerful to reduce the speed of the engine even at 19,000 feet altitude. Referring to the level flight at this altitude, it will be seen that the engine speed for the best setting is 20 revolutions per minute higher than at the full lean setting. Results of this flight test are typical of an exceptionally good type "A" control. Due to irregularities in the mechanical construction of the Zenith type U. S. 52 carburetors, many controls of this type do not have sufficient power to reduce the speed of the engine above 15,000 feet. While the particular control tested is satisfactory with regard to effectiveness to a high altitude, it was reported as extremely sensitive and difficult to adjust. The general opinion of pilots throughout the Air Service is that this type control is unsatisfactory, due to the difficulty of adjustment and to the wide variation between different carburetors.

TYPE "B" CONTROL.

Referring to Table 3, the dynamometer test of type "B" control shows only a slight saving in fuel consumption of the best position over the full rich position. The control is evidently quite powerful, since the full lean position stops the engine. This control was tested on the dynamometer with vacuum restriction holes of No. 56 drill size, one in each vacuum pipe. The diameter of the atmospheric hole in the valve was 0.161 inch. Due to the seeming excess of power of this control, it was thought best to reduce the vacuum restriction holes before the flight test. One vacuum pipe was therefore entirely plugged, and one was reduced to No. 60 drill size on each of the two carburetors. The atmospheric hole in the valve was not changed.

The flight test shown by Table 4 revealed a peculiar characteristic of the type "B" control. At any altitude above 10,000 feet the control could not be moved beyond position No. 10½ without stopping the engine. The cause of this is undoubtedly a reversal of flow through the compensator jet, causing air to be drawn into the main fuel passage and thus cutting down the supply of fuel to the main jet to such an extent that the engine stops. This may be explained by the fact that the compensator well was not connected to the float chamber but was separately vented to the space behind the venturis. The compensator wells were therefore at approximately atmospheric pressure at all times. The pressure on the float chamber, however, was greatly reduced as the valve was moved toward the lean position and at position No. 10½ it is very probable that the float chamber pressure became so much lower than the pressure in the compensator well that air was drawn from the well into the main fuel passage. This defect in the control is a serious objection and makes it impractical for further consideration. The pilot also reported that the control was quite sensitive at the lower altitudes, before reaching position No. 10½.

TYPE "C" CONTROL.

Table 5 shows the results obtained from the dynamometer test of type "C" control. The NA-D6 carburetor is supplied with an unusually large jet for purposes of acceleration, which gives a high fuel consumption in the full rich position. This fuel consumption can be greatly reduced by moving the control to the best position as shown in Table 5. The control appears fairly powerful, since the engine power was reduced by nearly 50 per cent in the full lean position. The flight test of this control is covered in Table 6. Readings were not taken during the climb. The results show that the limits of the control was reached somewhere between 12,000 and 16,000 feet altitude, since at 12,000 feet a reduction in engine speed could be obtained by moving to the lean position, while at 16,000 feet the highest engine speed was obtained in the full lean position. For pursuit airplanes the control should be effective to at least 20,000 feet, and therefore this control is unsatisfactory in its present form. This type of control was reported less sensitive than the type "A" control on the Zenith carburetor, although both work on the same principle. It is believed that the presence of the compensator system in the Zenith carburetor accounts for its greater sensitiveness.

TYPE "D" CONTROL.

The results of the dynamometer test of type "D" control are not available, but it is believed that they would be similar to those obtained on the type "C" control, since the chief difference between the two is in the type of valve used. The location of the source of suction is the same in both cases, although the atmospheric vents are in different positions.

Table 7 shows that the type "D" control reached its limit of effectiveness at 16,000 feet or lower, since at this altitude the full lean position gave the highest revolutions per minute.

TYPE "E" CONTROL.

The dynamometer tests of type "E" control, Table 8, show this control to be considerably more powerful than type "C." This is to be expected, since the size of the main jet is smaller, and therefore the type "E" control, which is the same as type "C" in all other respects, will give a leaner mixture for a given setting of the lever.

The flight test covered in Table 9 shows that this control was fully effective at 20,000 feet, a drop of nearly 100 revolutions per minute being obtainable from the best to the full lean position. This control appears to be quite satisfactory except that it still retains the considerable sensitiveness inherent in the "back-suction" type.

TYPE "F" CONTROL.

Dynamometer tests covered in Table 10 show this control to have very little effect as a fuel saver and to have very little power, since the engine operation is only slightly affected by moving to the full lean position. The flight test covered in Table 11 shows that a drop in speed could not be obtained by means of this control above 20,000 feet. The limit of effectiveness is probably reached between 15,000 and 20,000 feet altitude. Since this is the only flight which has been obtained with this type of control, the results should not be considered as entirely conclusive. From dynamometer tests of car-

buretors equipped with this type of control the indications are that it is not nearly as powerful as the flight test results quoted in Table 11 seem to indicate. In this connection it should be noted that at an altitude of 5,000 feet a reduction of only 40 revolutions per minute is effected between the best and full lean positions of the control. Tests on many carburetors equipped with an air bleed to the main fuel passage have shown that the metering characteristics of the carburetor are greatly affected by a change in the relative size of the main jet and air bleed. It is considered safe to assume, therefore, that the type "F" control would give different metering characteristics of the carburetor at different settings of the control valve. This consideration leads to the conclusion that this type of control is not worthy of further development.

TYPE "G" CONTROL.

Dynamometer tests of the type "G" control showed it to be no more effective than the type "F" and flight tests were, therefore, not conducted.

TYPE "H" CONTROL.

The dynamometer tests covered in Table 12 show that some saving in fuel is effected by this control as between the best and full rich positions and that it will stop the engine in the full lean position. The flight test covered by Table 13 indicates an extremely powerful control, 4 divisions out of 10 being all that could be used at 20,000 feet. Referring to the level flight results, it will be seen that at this altitude the engine would stop in the full lean position of the control.

Results of this test are very similar to the results obtained on the test of the type "B" control. It will be noted that when position No. 4 was reached at 16,000 feet, the control could not be moved any farther with increasing altitude. This indicates that a reversal of flow through the compensator may have taken place in a manner similar to that which was indicated with the type "B" control.

The extreme power of this control could be remedied by locating the ends of the suction pipes at a position where the depression was considerably less than it is at the center of the venturi nozzles. The inherent sensitiveness of this type of control, together with the reversal of flow through the compensator, make it unsuitable for further development.

In conclusion, it is believed that results of these tests indicate so many inherent disadvantages of the back-suction control that serious consideration should be given to the development of controls working on entirely different principles. The auxiliary air-port control, preliminary tests of which are covered by references Nos. 6 and 7, appears to be a promising arrangement. This type of control has the great advantage over the back-suction type in that it does not interfere with the normal functioning of the various parts of the carburetor, such as the compensator jet. It should also be considerably less sensitive, due to the fact that a large volume of air must be handled and small movements of the control valve will not cause very large changes in the total volume of air passing through the valve. Another promising form of control is one using some method of changing the rate of flow of gasoline to the nozzles by mechanical means.

TABLE 1.—*Dynamometer test of type "A" control (standard U. S. 52).*

Carburetor: Zenith U. S. 52.
Engine: Liberty. Model: 12A.
Date: July 15, 1920.

FULL THROTTLE RUN ON DYNAMOMETER.

Position of control valve.	R. P. M.	Corrected B. H. P.	Float chamber vac. in. H_2O.	Fuel cons. Lb. per hp. hr.
Full rich	1,730	404	6.2	0.537
Best	1,720	399	7.4	.513
Full lean [1]	1,300	230	6.2	.523

[1] Running unsteady in lean position.

Carburetor setting:
Chokes, 36 mm. diameter.
Main jets, 1.65 mm. diameter.
Compensating jets, 1.70 mm. diameter.

TABLE 2.—*Flight test of type "A" control.*

Airplane No.: DH-4, P-109.
Engine: Liberty "12."
Caburetor Zenith U. S. 52. Standard altitude control valve, type "A."
Propeller: 8-45.
Barometer: 29.276.
Ground temperature: 83° F.

FULL THROTTLE CLIMB TO SERVICE CEILING.

Time, min.	Alt., feet.	R.P.M.	Setting alt. control.	Air speed, M.P.H.	Flow-meter, inches.	Temperature. Strut. ° F.	Temperature. Air. Scoop, ° F.
......	0	1,540	0	....	5.4	83	90
1.15	2,000	1,620	0	65	5.5	70	82
3.10	4,000	1,630	0	63	5.5	61	79
5.25	6,000	1,620	0	66	5.2	54	77
8.00	8,000	1,600	0	65	5.0	48	70
11.00	10,000	1,580	1	63	4.7	47	73
14.45	12,000	1,570	3	63	4.7	40	70
19.20	14,000	1,550	5	60	4.4	30	62.6
27.00	16,000	1,530	9	58	4.0	22	61
42.30	18,000	1,520	11	56	3.8	10	48
56.35	19,000	....	12	....	3.7	....	....

LEVEL FLIGHT—SERVICE CEILING 19,000 FEET.

	R. P. M.	Setting alt. control.	Air speed, M. P. H.	Flow-meter, inches.	Fuel cons. gals. per hr.
Full throttle	1,550	Best, 12	....	....	....
	1,540	Rich, 0	....	....	....
	1,530	Lean, 15	....	....	....

LEVEL FLIGHT—ALTITUDE, 15,600 FEET.

	R. P. M.	Setting alt. control.	Air speed, M. P. H.	Flow-meter, inches.	Fuel cons. gals. per hr.
Full throttle	1,640	Best, 9	65	4.3	25.9
	1,640	Rich, 0	68	4.4	26.5
	1,240	Lean, 15	60	4.1	25.3

Remarks:
Altitude control, full lean at 15 divisions.
Lean position at 5,600 feet. Motor cut out.
Full throttle at 11,000 feet, revolutions per minute varying from 900 to 1,600 in lean position, 400 revolutions per minute less at same altitude; revolutions per minute steady, lean position.
Carburetor setting:
Chokes, 36 mm. diameter.
Main jets, 1.65 mm. diameter.
Compensating jets, 1.70 mm. diameter.

Table 3.—*Dynamometer test of type "B" control (valve on crank case).*

Four No. 56 drill size vacuum bleed holes; diameter of atmospheric hole in valve, 0.161 inch.
Carburetor: Zenith U. S. 52.
Engine: Liberty. Model: 12A.
Date: June 14, 1920.

FULL THROTTLE RUN ON DYNAMOMETER.

Position of control valve.	R. P. M.	Corrected B. H. P.	Float chamber vac. in. H_2O.	Fuel cons., lb. per hp. hr.
Full rich	1,720	402	4.0	0.548
Best	1,730	401	4.8	.544
Full lean	Engine stopped.			

Carburetor setting:
Chokes, 36 mm. diameter.
Main jets, 1.65 mm. diameter.
Compensating jets, 1.70 mm. diameter.

Table 4.—*Flight test of type "B" control.*

Date: July 8, 1920.
Airplane No.: DH-4, P-100.
Engine: Liberty 12A.
Carburetor: Zenith U. S. 52 type (B) control valve (air hole, 0.161 inch diameter 2 No. 60 drill size vacuum bleed holes.)
Propeller: 8-45.
Barometer: 29.36.
Ground temperature: 66° F.

FULL THROTTLE CLIMB TO SERVICE CEILING.

Time, min.	Alt., feet.	R. P. M.	Setting alt. control.	Air speed, M. P. H.	Flow-meter, inches.	Temperature. Strut.	Temperature. Air scoop.
						°F.	°F.
0	0	1,500	0	60	0	74	86
1.54	2,000	1,540	6	70	7	68	82
4.12	4,000	1,560	9	68	7	62	79
6.48	6,000	1,560	9½	68	7	52	72
9.42	8,000	1,580	10	67	6.8	48	68
12.36	10,000	1,600	10½	68	5	38	54
16.00	12,000	1,560	10½	64	4.7	27	52
20.48	14,000	1,540	10½	62	5.2	24	52
28.42	16,000	1,540	10½	66	(?)	20	50
38.24	17,500	1,540	10½	62	(?)	10	50

Remarks:
Altitude control full lean at 15 divisions.
Impossible to get more adjustment above 10,000 feet without stopping engine.
Carburetor setting:
Chokes, 36 mm. diameter.
Main jets, 1.65 mm. diameter.
Compensating jets: 1.70 mm. diameter.

Table 5.—*Dynamometer test of type "C" control (standard NA-D6).*

Carburetor: Stromberg NA-D6.
Engine: Hispano-Suiza. Model: "H." Mfg. No. 19.
Date: June 21, 1920.

FULL THROTTLE RUN ON DYNAMOMETER.

Position of control valve.	R. P. M.	Corrected B. H. P.	Float chamber vac. in. H_2O.	Fuel cons., lb. per hp. hr.
Full rich	1,800	325	0.3	0.632
Best	1,800	324	11.0	.458
Full lean	1,800	174	18.0	(1)

[1] Back firing.

Carburetor setting:
Chokes, 1[illegible] inches diameter.
Main jets, No. 32 drill.

Table 6.—*Flight test of type "C" standard Stromberg control.*

Engine: Hispano-Suiza. Model: "H."
Airplane: XB-1A P-90.

Altitude, feet.	R. P. M., level flight.	Position of control.
20,000	1,620	[1] Best 10
16,000	1,680	[2] Best 7
	1,730	Lean 10
12,000	1,755	Best 6
	1,735	Lean 10
8,000	1,770	Best 5
	1,765	Lean 10

[1] Full lean.
[2] At 16,000 feet the pilot believed that he had the best setting at 7 points on control, whereas the best appeared to be full lean.

The control was divided in movement into 10 equal parts, numbered from 0 (full rich) to 10 (full lean).
The engine would not run in the full rich position at any altitude where a speed course was made.
Carburetor setting:
Chokes, [illegible] inches diameter.
Main jets, No. 32 drill size.

Table 7.—*Flight test of type "D" Engineering Division two-way mixture control.*

Engine: Hispano-Suiza. Model: "H."
Airplane: XB-1A, P-90.

Altitude, feet.	R. P. M., level flight.	Position of control.
20,000	1,610	Lean 10
	1,580	Rich 6
16,000	1,770	Lean 10
	1,745	Rich 4
12,000	No readings because of clouds.	

Best position was full lean.
Control movement divided into 10 equal parts.
The control was set full lean on the climb at about 11,000 feet, and at 12,000 feet on level flight it is believed that full lean was the best setting.
Carburetor setting:
Chokes, 1[illegible] inches diometer.
Main jets, No. 32 drill size.

Table 8.—*Dynamometer test of type "E" control.*

Carburetor: Stromberg. Model: NA-D6 (MOD).
Engine: Hispano-Suiza. Model: "H."
Date: May 23, 1921.

FULL THROTTLE RUN ON DYNAMOMETER.

Position of control valve.	R. P. M.	Corrected B. H. P.	Float chamber vac. in. H_2O.	Fuel cons. lb. per hp. hr.
Full rich	1,800	325	....	0.518
Best	1,800	322	....	.470
Full lean	Engine will not run.			

Carburetor setting:
Chokes, 1[illegible] inches diameter.
Main jets, 35 drill size.
Air bleeds, No. 46 drill size.

Table 9.—*Flight test of type "E" control on special NAD–6 (MOD.).*

Engine: Hispano-Suiza. Model: "H."
Airplane: XB–1A, P–90.

Altitude, feet.	R. P. M., level flight.	Position of control.
20,000	1,655	Full lean 10
	1,670	Full rich 2
	1,750	Best 4
16,000	1,760	[1] Full lean 8
	1,775	Full rich 2
	([2])	Best 4
12,000	1,715	[1] Full lean 7
	1,815	Full rich 2[2]
	1,820	Best 4

[1] Positions noted are leanest possible for smooth operation. Full lean was actually position No. 10.
[2] Pilot came down before reading was taken.

Control movement divided into 10 equal parts.
Carburetor setting:
Chokes, 1[illegible] inches diameter.
Main jets, No. 35 drill size.
Air bleeds, No. 46 drill size.

Table 10.—*Dynamometer test of type "F" control (standard control on Packard carburetor).*

Carburetor: Packard double venturi.
Engine: Packard. Model: 1A–744.
Date: July 19, 1920.

FULL THROTTLE RUN ON DYNAMOMETER.

Position of control valve.	R. P. M.	Corrected B. H. P.	Float chamber vac. in. H_2O.	Fuel cons., lb. per hp. hr.
Full rich	1,605	184	0	0.475
Best	1,611	183	0	.474
Full lean	1,595	156	0	.466

Runs smoothly in full lean position.
Carburetor setting:
Chokes, 35 mm. diameter.
Main jets, No. 49 drill.
Compensating jets, No. 49 drill.

Table 11.—*Flight test of type "F" standard Packard control on Packard double-Venturi carburetor.*

Date: September 7, 1920. Hour: P. m.
Plane: P–144 Fokker.
Barometer: 29.428 in. hg.
Ground temperature 25° C.
Pilot: Sergeant MaDan.
Nature of test: Packard carburetor test.
Test No. 512–20.

Time, min.	Alt., feet.	R. P. M.	Setting alt. control.	Air speed, M. P. H.	Strut temp., °F.
0.8	2,000	1,750	2	80	65
2.3	4,000	1,740	3	80	55
3.8	6,000	1,740	3½	76	46
5.6	8,000	1,730	6	75	40
7.9	10,000	1,720	6	75	35
10.5	12,000	1,720	6½	74	30
13.8	14,000	1,690	6½	72	24
17.6	16,000	1,680	7½	70	20
22.2	18,000	1,680	9	68	12
28.3	20,000	1,660	10	65	2
38.7	21,800	1,620	10	60	5

Control full lean at 10.

Table 11.—*Flight test of type "F" standard Packard control on Packard double-Venturi carburetor*—Continued.

LEVEL FLIGHT—SERVICE CEILING 21,800 FEET.

	R. P. M.	Setting alt. control.		Air speed, M. P. H.
Full throttle	1,700	Best	10	72
	1,460	Rich	0	60
	....	[1] Lean	......	....

LEVEL FLIGHT—ALTITUDE 20,000 FEET.

Full throttle	1,740	Best	10	82
	1,660	Rich	0	75
	1,740	Lean	10	[1] 82

LEVEL FLIGHT—ALTITUDE 15,000 FEET.

Full throttle	1,890	Best	8	110
	1,850	Rich	0	105
	1,820	Lean	10	102

LEVEL FLIGHT—ALTITUDE 10,000 FEET.

Full throttle	1,920	Best	3	128
	1,920	Rich	0	128
	1,900	Lean	10	128

LEVEL FLIGHT—ALTITUDE 5,000 FEET.

Full throttle	2,000	Best	0	140
	2,000	Rich	0	140
	1,960	Lean	10	136

[1] Same as best.

Remarks: As a whole, control does not affect revolutions per minute very much. Smoothness of operation is obtained, however, by its use (at high altitudes).
Carburetor setting:
Chokes, 35 mm. diameter.
Main jets, No. 49 drill.
Compensating jets, No. 49 drill.

Table 12.—*Dynamometer test of type "H" control (two-way back-suction valve on Packard carburetor).*

Carburetor: Packard double venturi.
Engine: Packard. Model: 1A–744.
Date: July 20–21, 1920.

FULL THROTTLE RUN ON DYNAMOMETER.

Position of control valve.	R. P. M.	Corrected B. H. P.	Float chamber vac. in. H_2O.	Fuel cons., lb. per hp. hr.
Full rich	1,608	182	0.4	0.505
Best	1,605	179	.4	.474
Full lean	Engine stopped.			

Carburetor setting:
Chokes, 34 mm. diameter.
Main jets, No. 49 drill.
Compensating jets, No. 49 drill.

TABLE 13.—*Flight test of type "H" control on Packard double-venturi carburetor.*

Date: September 13, 1920. Hour: P. m.
Plane: P-144 Packard Fokker.
Barometer: 29.27 in. hg.
Ground temperature, 77° F.
Pilot: Sergeant MaDan.
Nature of test: Carburetor test.
Test No. 512-20.

FIRST FLIGHT WITH TYPE "H" CONTROL.

Time, min.	Alt., feet.	R. P. M.	Setting alt. control.	Air speed, M. P. H.	Strut Temp., °F.
0	0	0	0	0	0
1.2	2,000	1,720	2	76	70
2.7	4,000	1,700	$2\frac{1}{3}$	76	60
4.4	6,000	1,700	$2\frac{1}{2}$	74	53
6.4	8,000	1,700	3	70	50
8.6	10,000	1,670	3	70	45
11.2	12,000	1,660	3	68	38
14.6	14,000	1,660	3	68	32
18.0	16,000	1,650	4	66	25
25.5	18,000	1,640	4	64	20
36.0	20,000	1,600	4	60	9

Control full lean at 10.

TABLE 13.—*Flight test of type "H" control on Packard double-venturi carburetor*—Continued.

LEVEL FLIGHT—SERVICE CEILING 20,000 FEET.

	R. P. M.	Setting alt. control.	Air speed, M. P. H.	Strut Temp., °F.
Full throttle.........	1,650	Best 4	76	9
	1,650	Rich 0	76	9
	Cut out.	Lean 10	....	....

Remarks:
Altitude adjustment too sensitive; at 20,000 feet, one sixty-fourth of an inch either way from best adjustment will lose revolutions per minute.
Control full lean at position 10.

Carburetor setting:
Chokes, 34 mm. diameter.
Main jets, No. 49 drill.
Compensating jets, No. 49 drill.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV September 15, 1922 No. 369

THE BELLOWS (SYLPHON) FUEL PUMP FOR LIBERTY "12" AND WRIGHT MODEL "H" ENGINES

(Supersedes Report of April 28, 1921, Entitled "The Sylphon Fuel Pump," and Published in Information Circular No. 281)

(POWER PLANT SECTION REPORT)

▽

Prepared by H. C. Osborne
Engineering Division, Air Service
McCook Field, Dayton, Ohio
March 30, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

THE BELLOWS (SYLPHON) FUEL PUMP FOR LIBERTY "12" AND WRIGHT MODEL "H" ENGINES.

DESCRIPTION OF AND INSTRUCTIONS CONCERNING THE LIBERTY "12" AND WRIGHT "H" MODELS.

GENERAL.

It was advisable to change the name of this pump from "Sylphon fuel pump" to "Bellows Fuel Pump" because of the fact that the term "Sylphon" is a trade name for the first make of copper bellows used. Another make of bellows has also been found by test to be satisfactory for this work.

The bellows pump was designed to fill the need for an engine-driven fuel pump in order to obviate the use of air pressure where sufficient gravity head is not available. The name is derived from the metallic bellows, which is the characteristic feature of this pump. This type of pump was selected because it requires no packing gland and also because it gives a fixed maximum discharge pressure at high speeds and sufficient fuel at any speed, thus doing away with a relief valve. It is built in duplex form, so that in case one pumping unit fails the other unit will maintain sufficient fuel supply for all engine speeds.

Over two years of service of this type in flight and a 1,400-hour bench test at full capacity have shown this pump to be highly reliable. This performance, however, can be expected only when proper care, which is due any mechanism of this nature, is maintained.

At present this pump is produced for use on the Liberty "12" and Wright model "H" engines. The only difference between the two models is in the drive shaft and base casting flange. The assembly drawing number of the Liberty "12" pump is 047280 and that of the Wright model "H" is 047281.

GENERAL DESCRIPTION.

The Liberty "12" pump will be described, but the description for the model "H" is the same except that the splined drive shaft (045289) and the base casting (045266) on the Liberty are replaced on the model "H" by parts Nos. 045280 and 045267 respectively. The nut on the end of the magneto drive shaft of the model "H" must be removed and replaced by nut (045458) which is furnished with the pump. The Liberty pump is driven directly from the crank shaft.

A four-pitch worm (045205) in Figure 1 meshes with a 32-tooth worm wheel (045291), giving an 8 to 1 reduction. The worm wheel is attached to a cam shaft (045284) which actuates cam follower rollers (045287) attached to cam followers (045286). The cam followers extend into the bellows flange (045259) to which the bellows (045308) is soldered. The upper end of the bellows is soldered to the bellows head plate (045436), which is secured in position by machine screws (SP–2446). The bellows chamber (047277) also contains the inlet and outlet valve assemblies (047282) and (045276) respectively. As the worm rotates the worm wheel on the cam shaft the cams move the plungers down only, admitting fuel from the main tank to the bellows which is returned to its original position by the spring (045282) designed to give a maximum pressure of 4½ pounds per square inch with a closed discharge.

The worm drive shaft (045289) is threaded on to the worm and butts against the ball bearing. The worm bearing cage (045260) holds the bearing in position. The worm bearing cage retainer (045261) is grooved for felt packing to keep oil in the pump, and fits just outside of the worm bearing cage. The worm bearing cage and the worm bearing cage retainer are attached to the pump base by machine screws. The pump base cap (045302) is the bronze bearing on the other end of the worm.

The cam followers (045286) operate in the cam follower bearings lower (045304) and upper (045288), which are bronze bushings. The upper bearings are in the cam shaft support (045264) and the lower bearings in the pump base (045266). The cam shaft operates in aluminum bearings in the cam shaft support.

There are two intake and two outlet valves, each a unit, screwed into the valve chamber which is the upper part of the bellows chamber casting. The valve chamber has a partition, on one side of which are the two intake valves and on the other side the two outlet valves.

A hole. having ¼-inch pipe thread about one-half way down on one side of the pump, is utilized as a drain in case a gasket leaks or a bellows breaks.

Two outlets and two inlets are provided for convenience in installation. Only one of each is necessary. The pipe plugs are inserted to prevent dirt getting in valves in shipping and stocking.

The pipe plug in the bottom of the base is permanent and should be removed only to refill the base with lubricant.

OVERHAUL.

When an engine, having a pump attached, is received at a repair depot for overhaul, this pump should undergo the following test:

Shaft speed for all tests between 1,700 and 1,750 revolutions per minute.

Priming test.—With the suction side of the pump communicating with fuel tank in which the fuel level is at least 3 feet below the inlet to the pump, the pump must prime itself within 10 seconds, the pump being entirely dry at the start of this test.

Closed discharge test.—With the discharge closed, the pressure shall not exceed 4½ pounds per square inch.

Capacity test.—With the discharge throttled to give a discharge pressure of 1 pound per square inch measured *at the pump outlet*, the capacity shall be not less than 70 gallons per hour. With a discharge pressure of 2 pounds per square inch the capacity shall not be less than 35 gallons per hour.

If the pump passes this test, it may be replaced without overhaul. In case it does not pass the test, follow the directions below under "Disassembly." The following are a few aids in locating the trouble:

If the pump leaks at the small side opening, either a bellows is broken or else a gasket (045429) between the bellows and the chamber is defective.

If there is a leak around the top screws, it is probably due to a defective gasket (045429) between the bellows and the chamber or to a scratched or warped surface of the bellows head.

If the pump will not prime, or if it is under capacity, it may be due to a number of things: One or more of the four valves may have a chip holding it open, a plunger may not be free in its guides, or actuating spring may be weak. (See Precautions.)

DISASSEMBLY.

To disassemble the pump, first loosen, but do not remove, screws (SP-2446) on the top of the bellows chamber.

Remove screws which join bellows chamber, cam shaft support (045264), and pump base (045266).

Tap lightly on upper screws (SP-2446) until bond between gasket (045429) and bellows chamber is broken. (This prevents bellows from being stretched.)

Lift off bellows chamber (045277).

Carefully lift off cam shaft support (045264). This part carries the worm wheel and is doweled onto pump base (045266), giving correct alignment with worm (045305).

The worm wheel is removed by unscrewing machine screws (SV-2533).

The worm (045305) can be removed by withdrawing cotter on engine shaft (045289), unscrewing same, pulling worm bearing cage retainer (045261), worm bearing cage (045260), and ball bearing, then removing worm (045305).

The cam follower bearings upper (045288) and lower (045304), the pump base cap (045302), and worm bearing cage (045260) are of bronze, pressed in.

The four valve assemblies are in units. These can be removed by means of a broad screw driver or socket wrench

INSTALLATION.

The Liberty "12" pump has a splined drive which fits into the rear end of the crank shaft. It is attached by nuts holding it down to six studs on the rear of the crank case. Figure 2 shows this pump mounted.

The Wright model "H" pump has a square drive which fits into a special nut which replaces nut (11240) on the end of the magneto drive gear shaft (13127). It is attached to the rear end of the magneto bracket. Figure 3 shows this pump mounted.

Either "in" and either "out" may be used in piping these pumps. The "in" and "out" not used must be plugged. Care must be taken not to get dirt into the valve chamber when this work is done.

The ⅛-inch P. T. tapped hole about halfway down on one side should be piped through the bottom of the fuselage. This acts as a drain in case of gasket leak or other failure, thus reducing fire hazard, and making it less difficult to locate the trouble.

Figure 4 shows a typical piping installation using this type of pump.

PRECAUTIONS.

Study Figure 1 and read "Disassembly" carefully before attempting disassembly. Lock all screws with wire in reassembling.

The pump base should be thoroughly cleaned of lubricant, and about one-fifth of a pound of fresh vaseline put in every 300 hours of service.

Do not use rubber for gasket material. "Siegelite" should always be used.

Do not attempt to repair a leaky bellows

If a pump is under capacity, do not force it by increasing the tension of the actuating springs. Something else is wrong which might cause future trouble.

Actuating springs must have a tension of 12½ pounds, plus or minus one-fourth pound, when compressed at 1¼ inches.

In reassembling, see that bellows height from bottom of lower head to top of upper head is 1⅞ inches.

Before assembling, see that valves are clean and working properly.

In reassembling, before putting on bellows chamber, line up holes in top bellows heads, and no trouble should be experienced in threading screws into place.

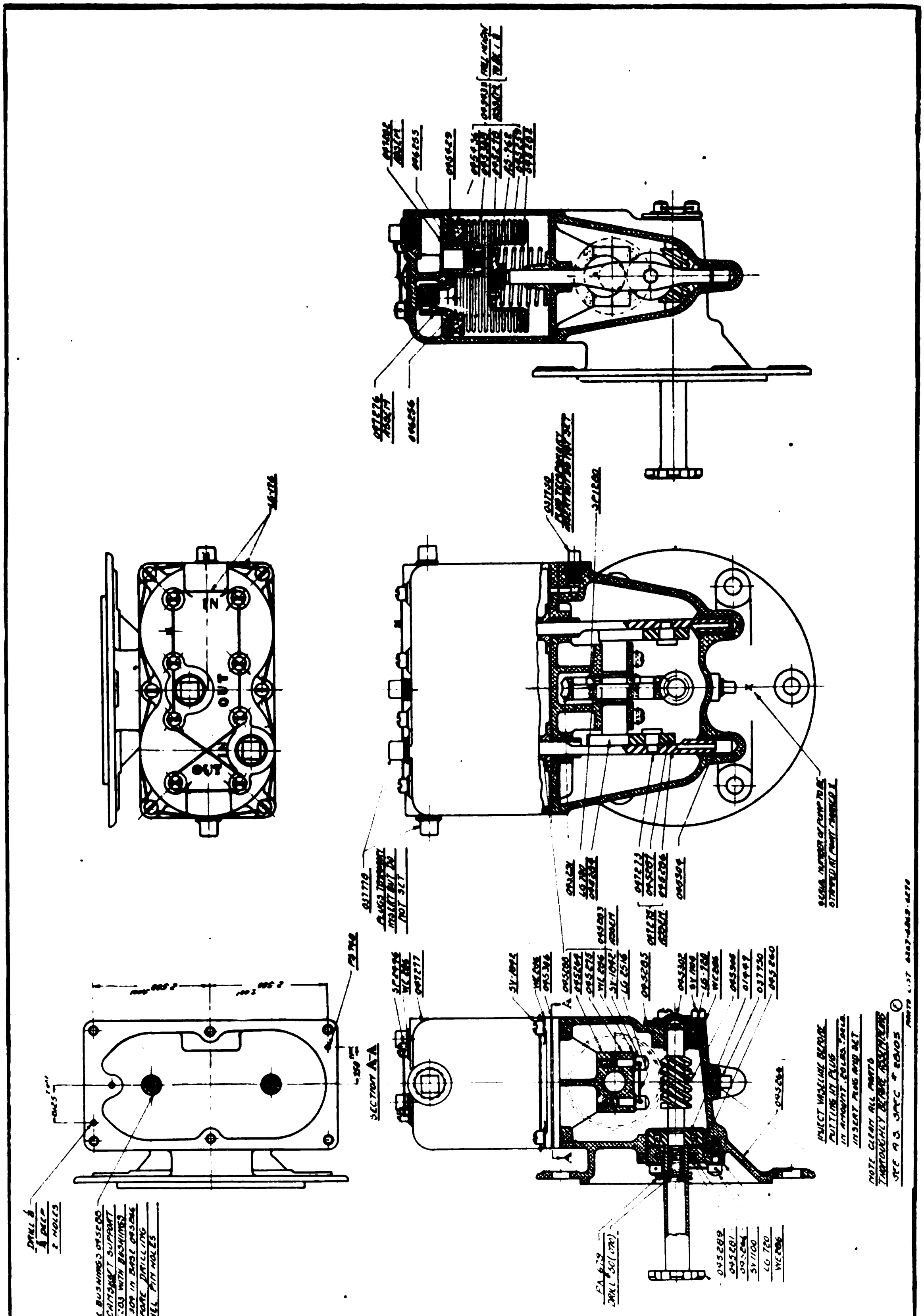


FIG. 1.—Three-view and sectioned assembly drawings of Liberty "12" pump.

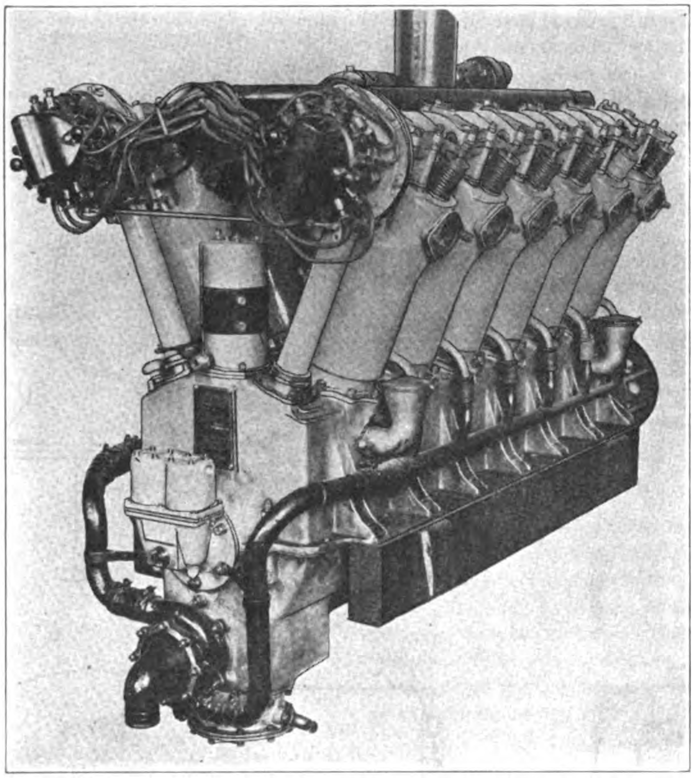


FIG. 2.—Pump on a Liberty "12" engine.

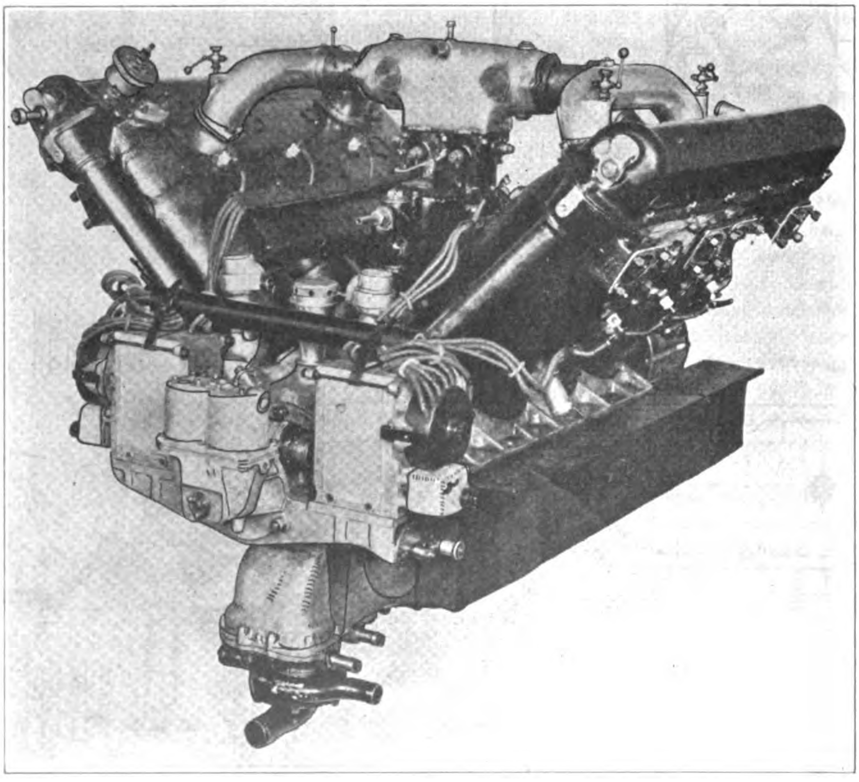


FIG. 3.—Pump on a Wright Model "H" engine.

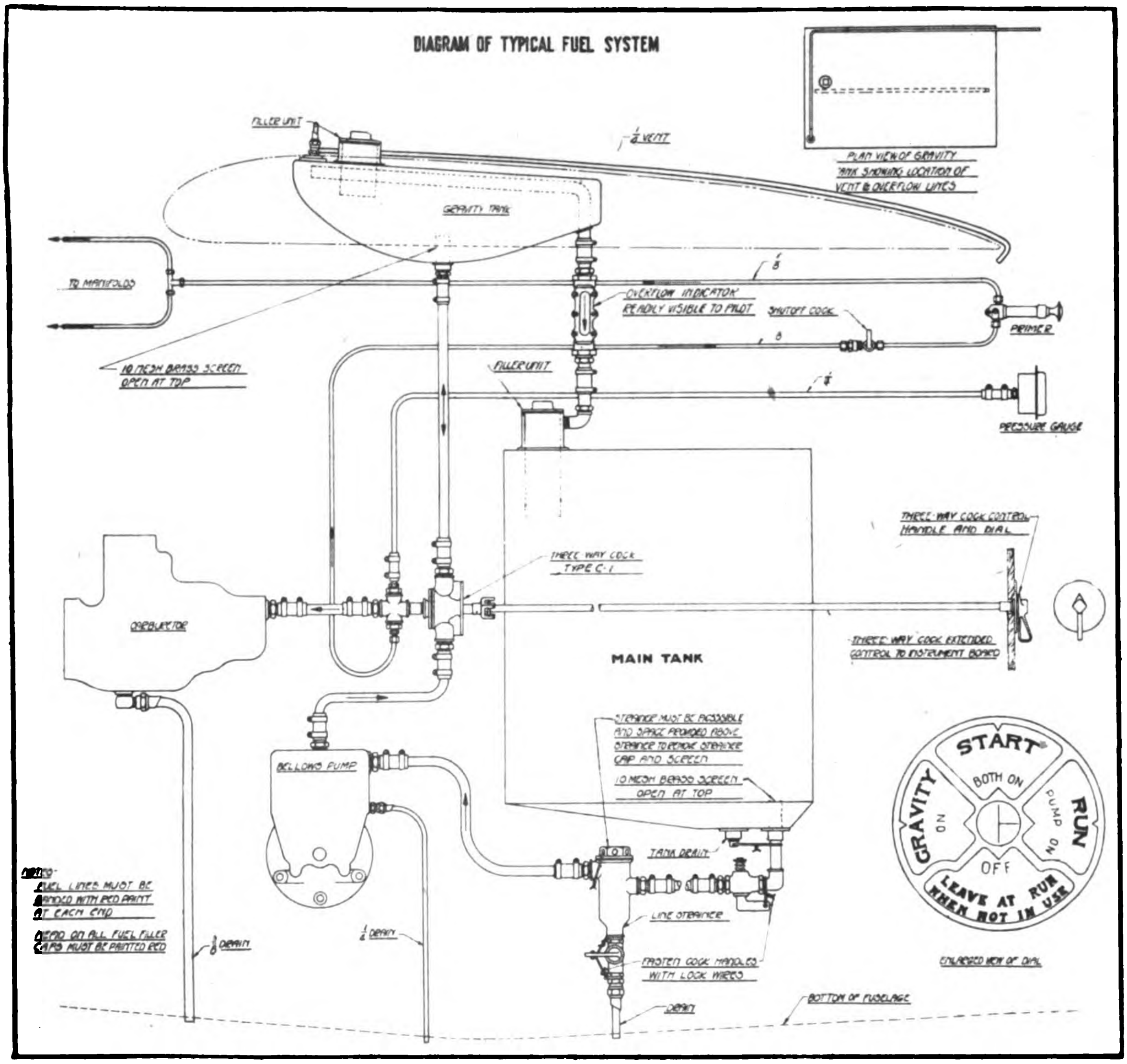


FIG. 4.—Ideal diagram of a fuel system employing the pump.

File No. D 52.46/28

(*C. A. S. I. C. 1.*)

AIR SERVICE INFORMATION CIRCULAR.

(AVIATION.)

CHANGES }
No. 1. }

WAR DEPARTMENT, AIR SERVICE,
January 1, 1923.

Page 3, columns 1 and 2, paragraph 2, under General Description, Air Service Information Circular, Vol. IV, No. 369, "The Bellows (Sylphon) Fuel Pump for Liberty '12' and Wright Model 'H' engines," are changed, by order of the Chief of Air Service, in accordance with a recommendation of the Engineering Division contained in a letter dated November 7, 1922, as follows:

Page 3, column 1, paragraph 2, under General Description, should read as follows:

A four-pitch worm (*045305*) in Figure 1 meshes with a 32-tooth worm-wheel (045291) giving an 8 to 1 reduction. The worm-wheel is attached to a cam shaft (045284) which (C. A. S. I. C. No. 1, Jan. 1, 1923.)

Page 3, column 2, should read as follows:

actuates cam follower rollers (045287) attached to cam followers (045286). The cam followers extend into the bellows flange (045289) to which the bellows (045308) is soldered. The upper end of the bellows is soldered to the bellows head plate (045436) which is secured in position by machine screws (SP–2446). The bellows chamber (047277) also contains the inlet and outlet valve assemblies (047282) and (*047276*) respectively. As the worm rotates the worm-wheel on the camshaft the cams move the plungers down only, admitting fuel from the main tank to the bellows which is returned to its original position by the spring (045282) designed to give a maximum pressure of 4½ pounds per square inch with a closed discharge. (C. A. S. I. C. No. 1, Jan. 1, 1923.)

23812—22

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1922

File D 52.411/Zenith/24 *McCOOK FIELD REPORT, SERIAL No. 1933*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV October 15, 1922 No. 370

TEST OF A ZENITH CARBURETOR, MODEL U. S. 52 FITTED WITH "PLAIN TUBE" AND BRITTON TYPE DISCHARGE NOZZLES

(POWER PLANT SECTION REPORT)

▽

Prepared by J. M. Miller, A. M. E.
Engineering Division, Air Service
McCook Field, Dayton, Ohio
May 10, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

TEST OF A ZENITH CARBURETOR MODEL U. S. 52 FITTED WITH "PLAIN TUBE" AND BRITTON TYPE DISCHARGE NOZZLES.

OBJECT OF TEST.

This test was conducted to determine the metering characteristics of the Zenith carburetor, Model U. S. 52, (1) as used in service on Liberty "6" and "12" aviation engines, (2) fitted as a "plain tube" carburetor (compensating fuel passage blank), and (3) with Britton type discharge nozzles.

CONCLUSIONS.

The "plain tube" setting retains the power and fuel consumption characteristics of the standard carburetor. The acceleration is good, but not equal to that of the standard setting, whereas the altimetric and load compensation are practically the same. It has no advantages as to operating characteristics over the standard setting. The acceleration of the Britton type discharge nozzle is definitely poor, making it impracticable for service use.

The Britton type discharge nozzle shows slightly less mixture enrichment up to 10,000 feet altitude, but a greater enrichment from 10,000 to 25,000 feet altitude than the standard setting. This nozzle has slight inherent load compensation if used in a strictly plain tube carburetor, that is, with a blank compensating jet in the Zenith U. S. 52. When used with the compensating jet which supplies fuel to the idle well only, this characteristic is not apparent, the load compensation being practically the same as that of the standard and the "plain tube" settings. The load compensation of the "plain tube" and Britton type discharge nozzle takes place through the idling passages.

DESCRIPTION.

The Britton type discharge nozzle was designed by Mr. K. B. Britton, of the Britton Carburetor Manufacturing Co. of Cleveland, Ohio, and consists of a cone-shaped nozzle with four outlet holes near the base of the cone, drilled at an angle of 45° with the center line. (See fig. 35.) This nozzle is screwed into the Zenith U. S. 52 carburetor body in place of the standard Zenith main jet and compensating discharge nozzle or cap jet. The threaded portion is long enough to blank off the compensating fuel passage, the compensating jet or metering orifice remaining in place to supply fuel to the idling well. The main metering orifice is screwed into the lower end of this discharge nozzle.

The "plain tube" arrangement was obtained by blanking the compensating fuel passage between the compensating metering jet and the discharge nozzle (see figs. 18 and 15). The compensating jet supplies fuel to the idling system only, as with the Britton type discharge nozzle.

METHOD OF TEST.

The runs made on this test may be divided into three general classes, (1) those conducted with the carburetor mounted on a Liberty "6" or "12" aviation engine on the dynamometer or torque stand to determine power, fuel consumption, and general operating characteristics, (2) those conducted in the carburetor test chamber to determine the metering characteristics of the carburetor with various settings, and (3) flight tests.

A Liberty "6" aviation engine was coupled to an electric cradle dynamometer and the following runs made with (1) the standard Zenith U. S. 52 setting, (2) Britton type discharge nozzles, and (3) the "plain tube" arrangement: several check runs at 1,700 revolutions per minute, full throttle, to determine the best setting, a full power run 1,200 revolutions per minute to 2,000 revolutions per minute, a propeller load run 1,700 revolutions per minute to 1,200 revolutions per minute, and runs to determine the acceleration. These runs were conducted and computations made as outlined in Engineering Division Report, Serial No. 1507. Domestic Aviation Gasoline, War Department Specification No. 2-40, was used during all the runs made on this test, including those in the carburetor test chamber. The time required for the engine to accelerate from 300 revolutions per minute to 1,200 revolutions per minute with rapid throttle opening and fixed electrical resistance was taken as a measure of acceleration in comparing the various carburetor setting and discharge nozzle combinations tried.

Runs were made with the Liberty "6" engine mounted on the torque stand to determine more accurately the propeller load and acceleration characteristics of the carburetor with the same nozzle arrangements as were used on the dynamometer runs. Five-minute fuel readings were made at full throttle, 1,500, 1,300, and 1,100 revolutions per minute, on a Liberty "12" engine on the torque stand with standard carburetors and with "plain tube" arrangement in the same carburetor.

The carburetor test chamber, used for determining the metering characteristics of this carburetor under various conditions of air flow and throttle opening, consists essentially of four parts, (1) a pump for producing the necessary air flow through the carburetor, (2) the box or test chamber proper in which the carburetor is mounted, (3) a Durley flat plate orifice for measuring the weight of air flow, and (4) a volumetric fuel measuring tank. The necessary manometers for measuring pressure differences at various points in the carburetor are also provided. Figures 16 and 17 show the box and manometer board.

The work in the carburetor test chamber was conducted in a manner to get a direct comparison of metering characteristics between the standard Zenith U. S. 52 carburetor and the same carburetor fitted with the "plain" and Britton type of discharge nozzles, and also to determine the effect of the component parts of the standard carburetor on mixture ratio. Runs simulating propeller load operation were made at ground level and 20,000 feet altitude and full throttle runs at each 5,000 feet altitude from

the ground level to 25,000 feet. The effect of float chamber vacuum was determined by taking several readings at various vacuums for each altitude increment up to 25,000 feet. In making runs in the carburetor test chamber two and often more readings were made for each condition of air flow, altitude, etc., and the results averaged.

Flight tests of the "plain tube" setting were made with a Liberty "6" engine mounted in airplane P–173 and with a Liberty "12" engine in airplane P–175. Flights were made to the service ceiling of each airplane and acceleration and general operation during maneuvers determined at various altitudes. Several cross-country flights were made with airplane P–175.

ANALYSIS OF RESULTS.

The operation of the Liberty "6" engine is practically the same with the "plain tube" arrangement as with the standard U. S. 52 setting. A slight difference in acceleration may be detected with a stop watch, the standard setting having the greater acceleration due probably to the fuel in the compensating fuel discharge nozzle and the idle well which is available as soon as the throttle is opened but is blanked off with the "plain tube" setting. The actual time in seconds for the engine to accelerate from 300 to 1,200 revolutions per minute with a fixed electrical resistance and rapid throttle opening was 5.4 for the "plain tube" and 4.8 for the standard setting. The acceleration of the engine with the Britton type discharge nozzle is definitely inferior to that obtained with the standard setting, the engine ceasing to fire if the throttle is opened quickly.

The fuel consumption curves for full throttle and propeller load operation are shown in Figures 1 and 2. The shape of the curves is practically the same for each setting tried indicating that load compensation is not seriously interfered with by blanking off the compensating fuel passage. The fact that compensation under these conditions takes place through the idle passages was clearly indicated by running the engine with blank compensating jets fitted in the standard or "plain tube" carburetor. Full throttle operation with the blank compensating jets was comparable to that of the standard or "plain tube" setting but on closing the throttle as on propeller load the mixture became so lean that the engine ceased firing.

Comparative curves of fuel flow and specific fuel consumption for the standard setting and the "plain tube" setting on a Liberty "12" mounted on the torque stand are shown in Figure 3. The fuel flow with the "plain tube" arrangement is approximately 8 per cent greater than that of the standard setting at cruising speeds, 1,400 to 1,600 revolutions per minute.

This difference in fuel flow does not check with the results obtained in the carburetor test chamber. (See curve sheet, fig. 11.) It is quite possible that part of the apparent increase in fuel flow, on the torque stand, of the "plain tube" setting over that of the standard was due to temperature and barometric differences. These atmospheric conditions indicate a greater density on the day when the "plain tube" carburetor was run, which would increase the amount of power required to drive the propeller at a given speed, thus increasing the amount of throttle opening required and hence the fuel flow.

The tabulated data on pages 22 and 23, most of which are shown in plotted form in Figures 4 to 14, indicate the character and results of the runs made in the carburetor test chamber.

The curves in Figure 4 indicate the altimetric compensation of the standard Zenith carburetor with the control in the full rich and full lean positions. The mixture enrichment[1] from ground level to 25,000 feet is 72.2 per cent with the control in the full rich position. The mixture range obtained by means of the mixture control is greatest at the ground, decreasing with increasing altitude. Ground level mixture may be maintained with the control to 15,000 feet altitude.

The altimetric compensation of the "plain tube" and Britton settings is shown by the curves in Figure 5. The enrichment of the "plain tube" setting from ground level to 25,000 feet in the full rich position is slightly less than that of the standard carburetor being 42.5 per cent as compared to 72.2 per cent. The enrichment of the Britton type discharge nozzle over the same altitude range is practically the same as that of the standard setting but has a slightly different form of mixture ratio curve, showing less enrichment up to 10,000 feet altitude and a greater enrichment between 10,000 feet and 25,000 feet altitude. The range of the mixture control is somewhat less for the plain tube than the standard setting giving ground level mixture to an altitude of approximately 12,500 feet.

Load compensation curves of the standard carburetor and setting are shown in Figure 6. The mixture enrichment on propeller load from 1,700 to 1,300 revolutions per minute is slight, 11.5 per cent at ground level, full rich, and approximately the same at 20,000 feet altitude, full rich and full lean. The greater enrichment of the mixture in the full lean position at ground level is through a range of mixture ratios much too lean for engine operation.

Mixture ratio characteristics of the "plain tube" setting on propeller load are shown in Figure 7. The change in mixture ratio is practically the same as that of the standard setting, the absolute values being slightly leaner. This latter condition is to be expected as the fuel flow through the compensating fuel passage was cut off. The curve obtained with the compensating jet blank indicates clearly that the compensation obtained with the "plain tube" setting takes place through the idling passages. This curve is characteristic for a plain jet in a single venturi, the mixture becoming lean as the throttle is closed.

The curve sheet, Figure 8, shows the load compensation of the Britton type discharge nozzle at ground level and 20,000 feet altitude. With the standard size compensating jet in place, so that compensation may take place through the idle passages, this nozzle gives practically the same mixture ratio change over propeller load as does the standard discharge nozzle with or without the compensating fuel passage blanked. With a blank compensating jet, however, the Britton type discharge nozzle shows slight inherent load compensation characteristics, the mixture becoming leaner as the throttle is closed but not to the same extent as with the standard discharge nozzle under the same conditions.

[1] Per cent mixture enrichment $= \dfrac{\left(\frac{1}{y} - \frac{1}{x}\right)}{\frac{1}{x}} \times 100$ where x = mixture ratio, lb. air/lb. fuel, ground level. y = mixture ratio lb. air/lb. fuel, 25,000 ft. altitude.

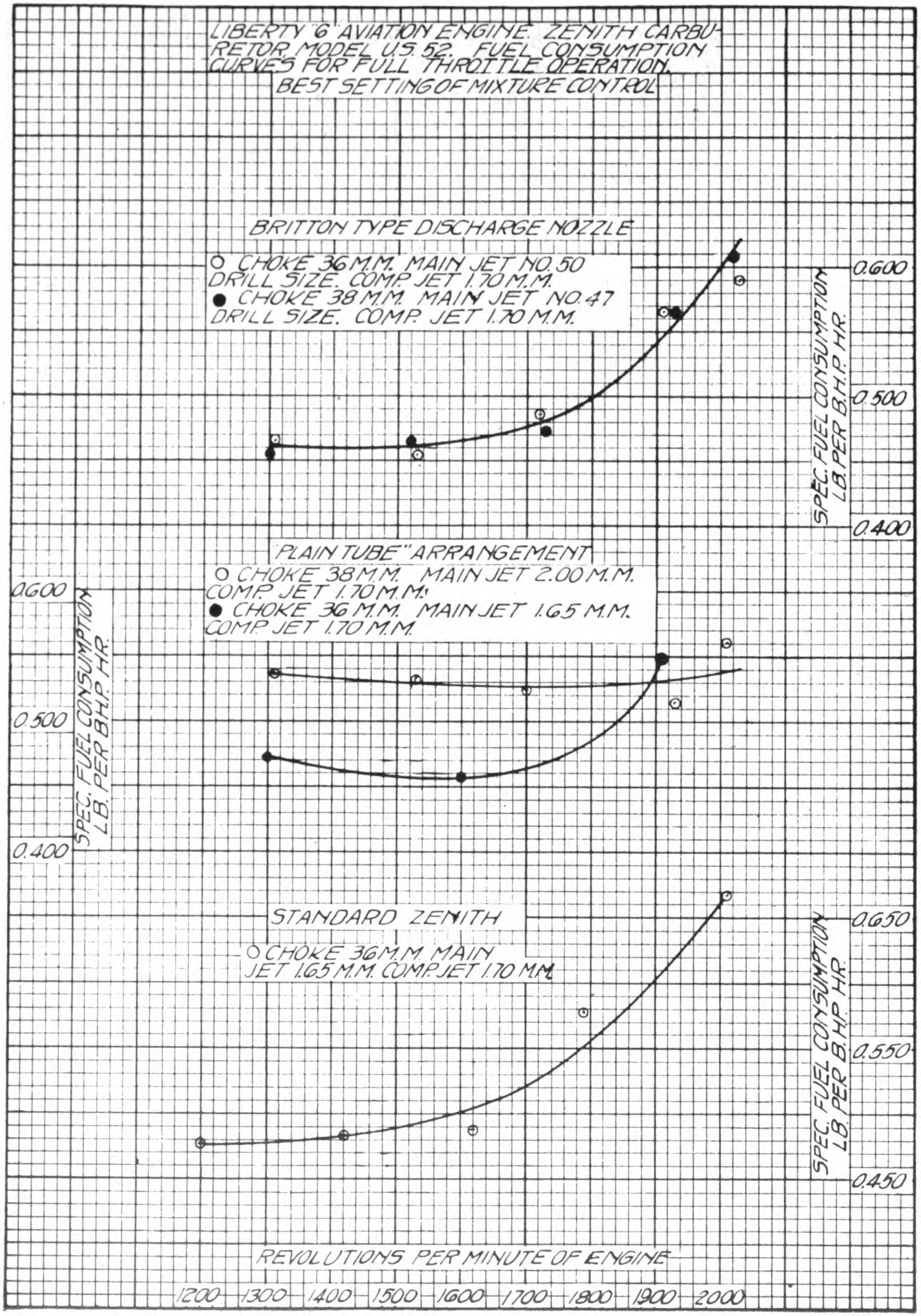

LIBERTY "6" AVIATION ENGINE. ZENITH CARBURETOR. MODEL U.S. 52. FUEL CONSUMPTION CURVES FOR FULL THROTTLE OPERATION. BEST SETTING OF MIXTURE CONTROL
BRITTON TYPE DISCHARGE NOZZLE
O CHOKE 36 M.M. MAIN JET NO. 50 DRILL SIZE. COMP. JET 1.70 M.M.
● CHOKE 38 M.M. MAIN JET NO. 47 DRILL SIZE. COMP. JET 1.70 M.M.
SPEC. FUEL CONSUMPTION LB. PER B.H.P. HR.
0.600
0.500
0.400
"PLAIN TUBE" ARRANGEMENT
O CHOKE 38 M.M. MAIN JET 2.00 M.M. COMP. JET 1.70 M.M.
● CHOKE 36 M.M. MAIN JET 1.65 M.M. COMP. JET 1.70 M.M.
SPEC. FUEL CONSUMPTION LB. PER B.H.P. HR.
0.600
0.500
0.400
STANDARD ZENITH
O CHOKE 36 M.M. MAIN JET 1.65 M.M. COMP. JET 1.70 M.M.
SPEC. FUEL CONSUMPTION LB. PER B.H.P. HR.
0.650
0.550
0.450
REVOLUTIONS PER MINUTE OF ENGINE
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIG. 1.

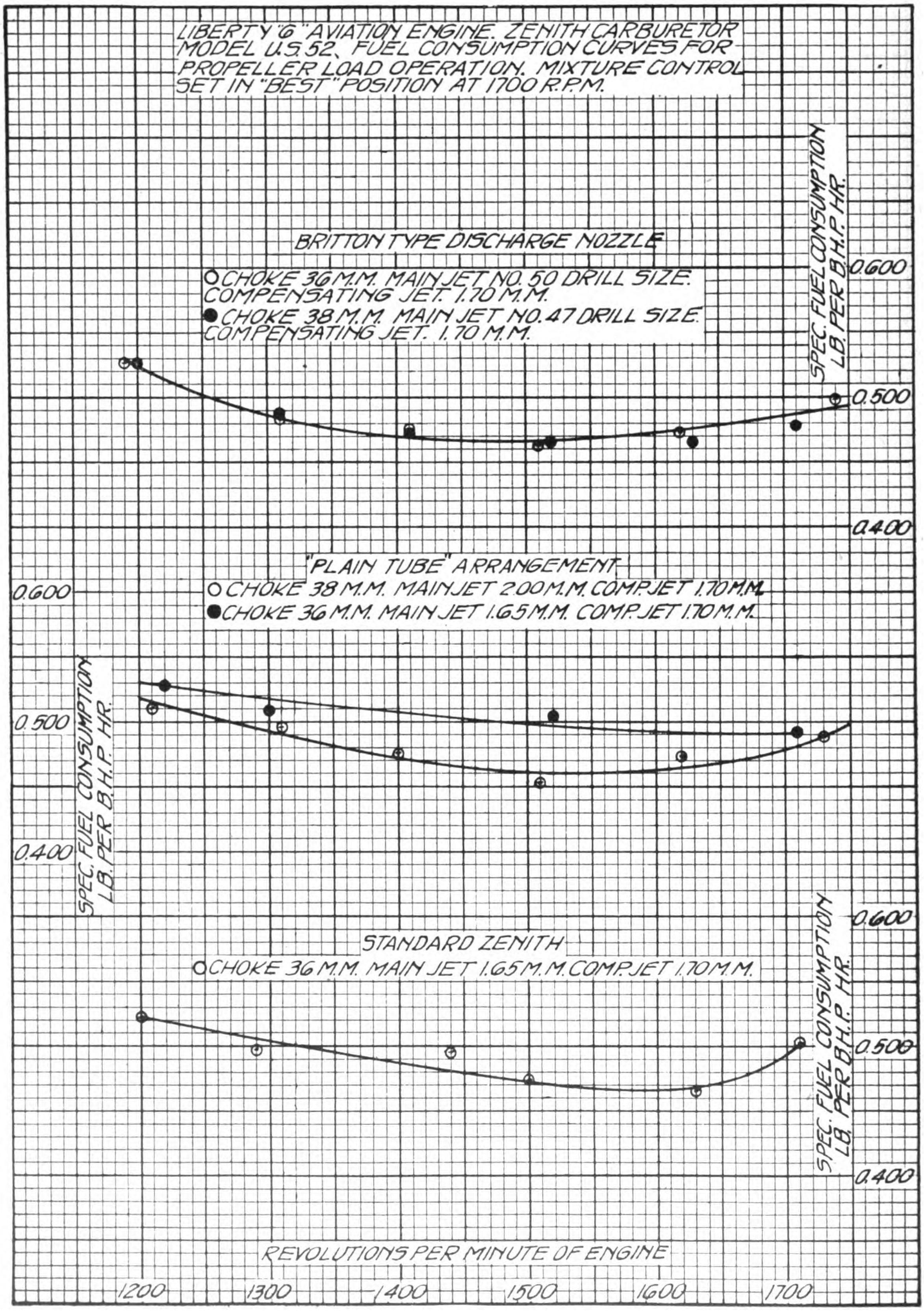

LIBERTY "6" AVIATION ENGINE. ZENITH CARBURETOR MODEL U.S. 52, FUEL CONSUMPTION CURVES FOR PROPELLER LOAD OPERATION. MIXTURE CONTROL SET IN "BEST" POSITION AT 1700 R.P.M.
BRITTON TYPE DISCHARGE NOZZLE
○ CHOKE 36 M.M. MAIN JET NO. 50 DRILL SIZE. COMPENSATING JET. 1.70 M.M.
● CHOKE 38 M.M. MAIN JET NO. 47 DRILL SIZE. COMPENSATING JET. 1.70 M.M.
SPEC. FUEL CONSUMPTION LB. PER B.H.P. HR.
0.600
0.500
0.400
"PLAIN TUBE" ARRANGEMENT.
○ CHOKE 38 M.M. MAIN JET 2.00 M.M. COMP. JET 1.70 M.M.
● CHOKE 36 M.M. MAIN JET 1.65 M.M. COMP. JET 1.70 M.M.
0.600
0.500
0.400
SPEC. FUEL CONSUMPTION LB. PER B.H.P. HR.
STANDARD ZENITH
○ CHOKE 36 M.M. MAIN JET 1.65 M.M. COMP. JET 1.70 M.M.
0.600
0.500
0.400
SPEC. FUEL CONSUMPTION LB. PER B.H.P. HR.
REVOLUTIONS PER MINUTE OF ENGINE
1200
1300
1400
1500
1600
1700

FIG. 2.

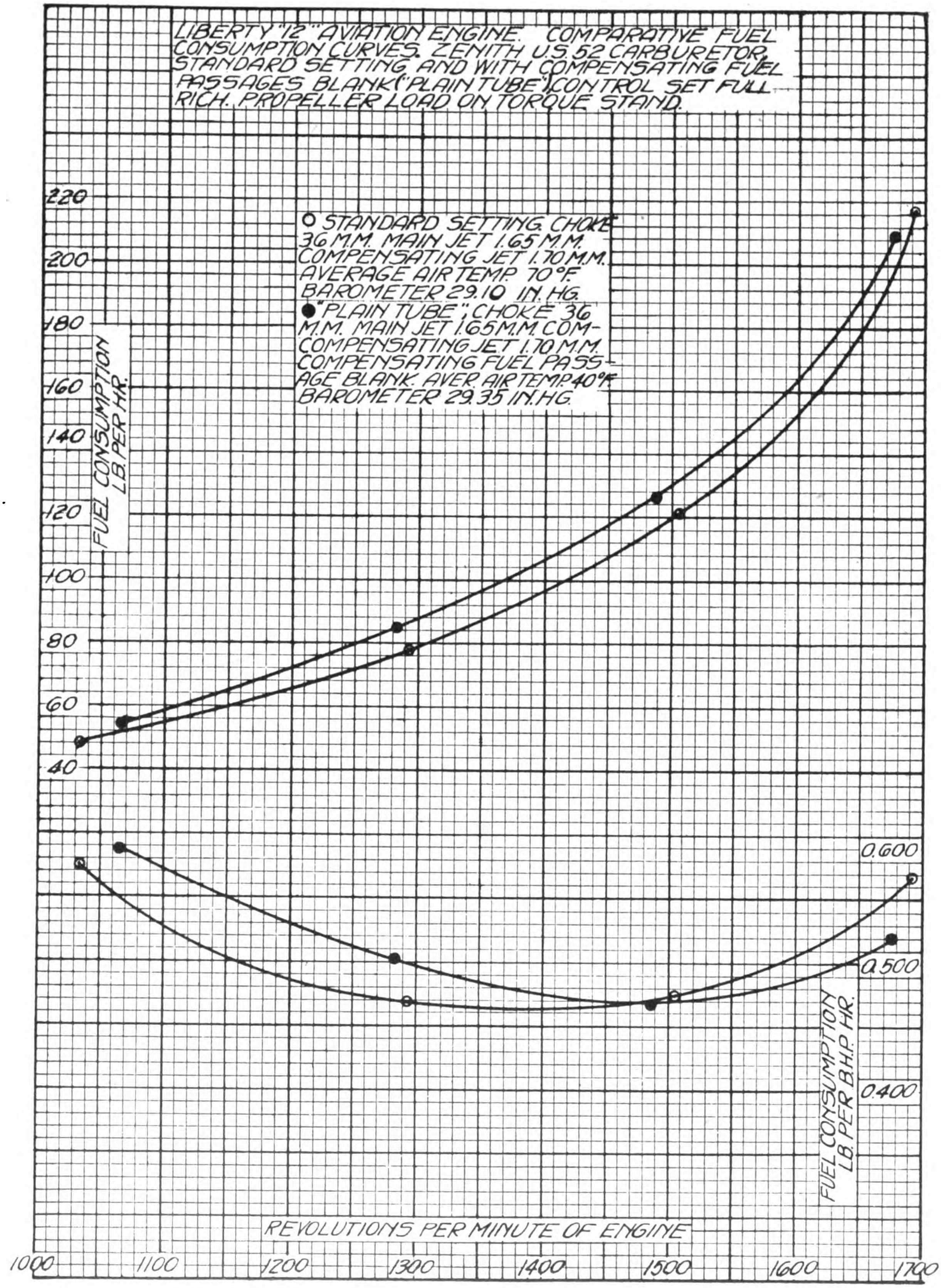

LIBERTY "12" AVIATION ENGINE. COMPARATIVE FUEL CONSUMPTION CURVES. ZENITH U.S. 52 CARBURETOR. STANDARD SETTING AND WITH COMPENSATING FUEL PASSAGES BLANK ("PLAIN TUBE") CONTROL SET FULL RICH. PROPELLER LOAD ON TORQUE STAND.
○ STANDARD SETTING. CHOKE 36 M.M. MAIN JET 1.65 M.M. COMPENSATING JET 1.70 M.M. AVERAGE AIR TEMP. 70°F. BAROMETER 29.10 IN. HG.
● "PLAIN TUBE"; CHOKE 36 M.M. MAIN JET 1.65 M.M. COMCOMPENSATING JET 1.70 M.M. COMPENSATING FUEL PASSAGE BLANK. AVER. AIR TEMP. 40°F. BAROMETER 29.35 IN. HG.
FUEL CONSUMPTION LB. PER HR.
220
200
180
160
140
120
100
80
60
40
0.600
0.500
0.400
FUEL CONSUMPTION LB. PER B.H.P. HR.
REVOLUTIONS PER MINUTE OF ENGINE
1000
1100
1200
1300
1400
1500
1600
1700

Fig. 3.

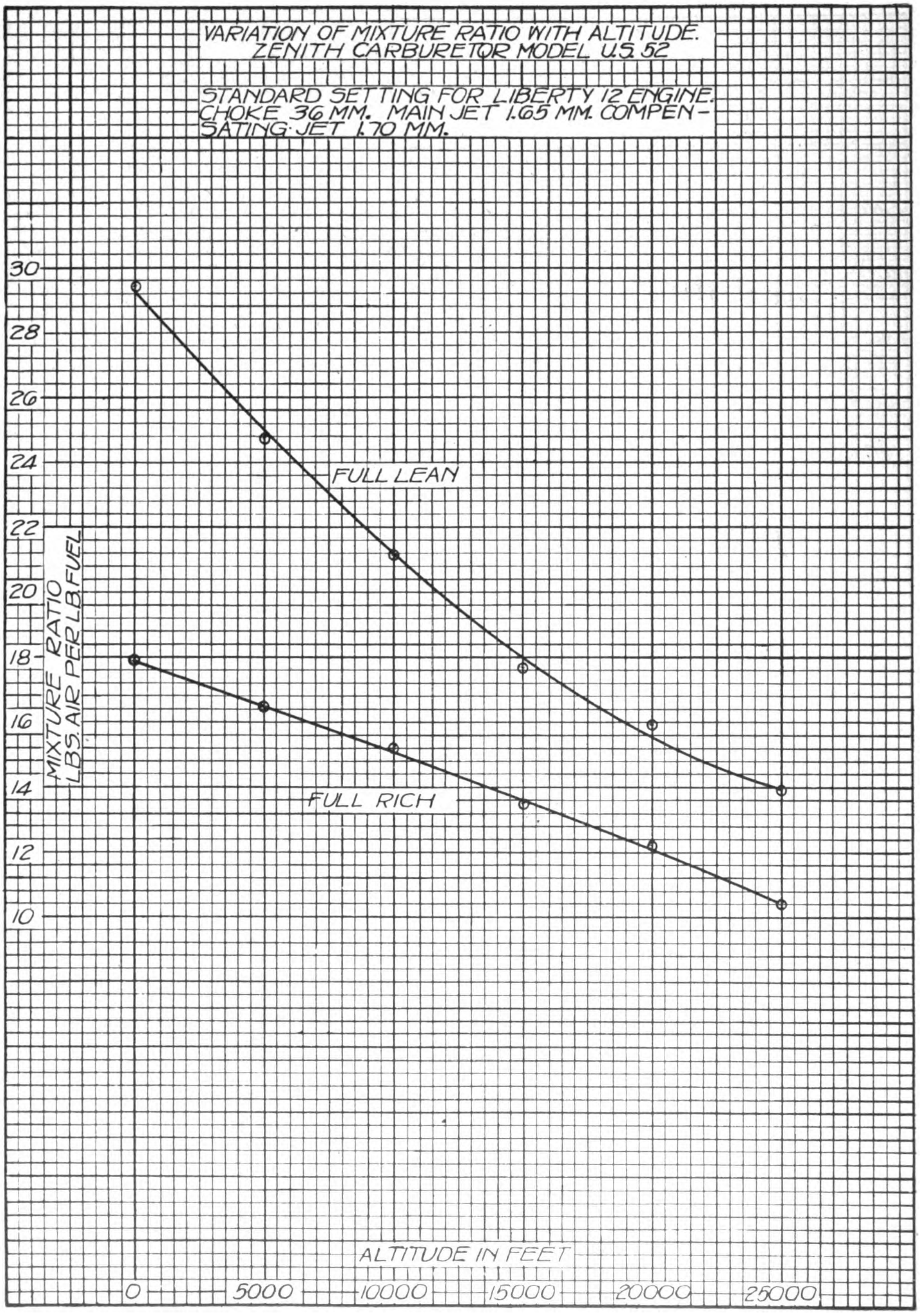

VARIATION OF MIXTURE RATIO WITH ALTITUDE.
ZENITH CARBURETOR MODEL U.S. 52
STANDARD SETTING FOR LIBERTY 12 ENGINE.
CHOKE 36 MM. MAIN JET 1.65 MM. COMPENSATING JET 1.70 MM.
FULL LEAN
FULL RICH
MIXTURE RATIO
LBS. AIR PER LB. FUEL
30
28
26
24
22
20
18
16
14
12
10
ALTITUDE IN FEET
0
5000
10000
15000
20000
25000

Fig. 4.

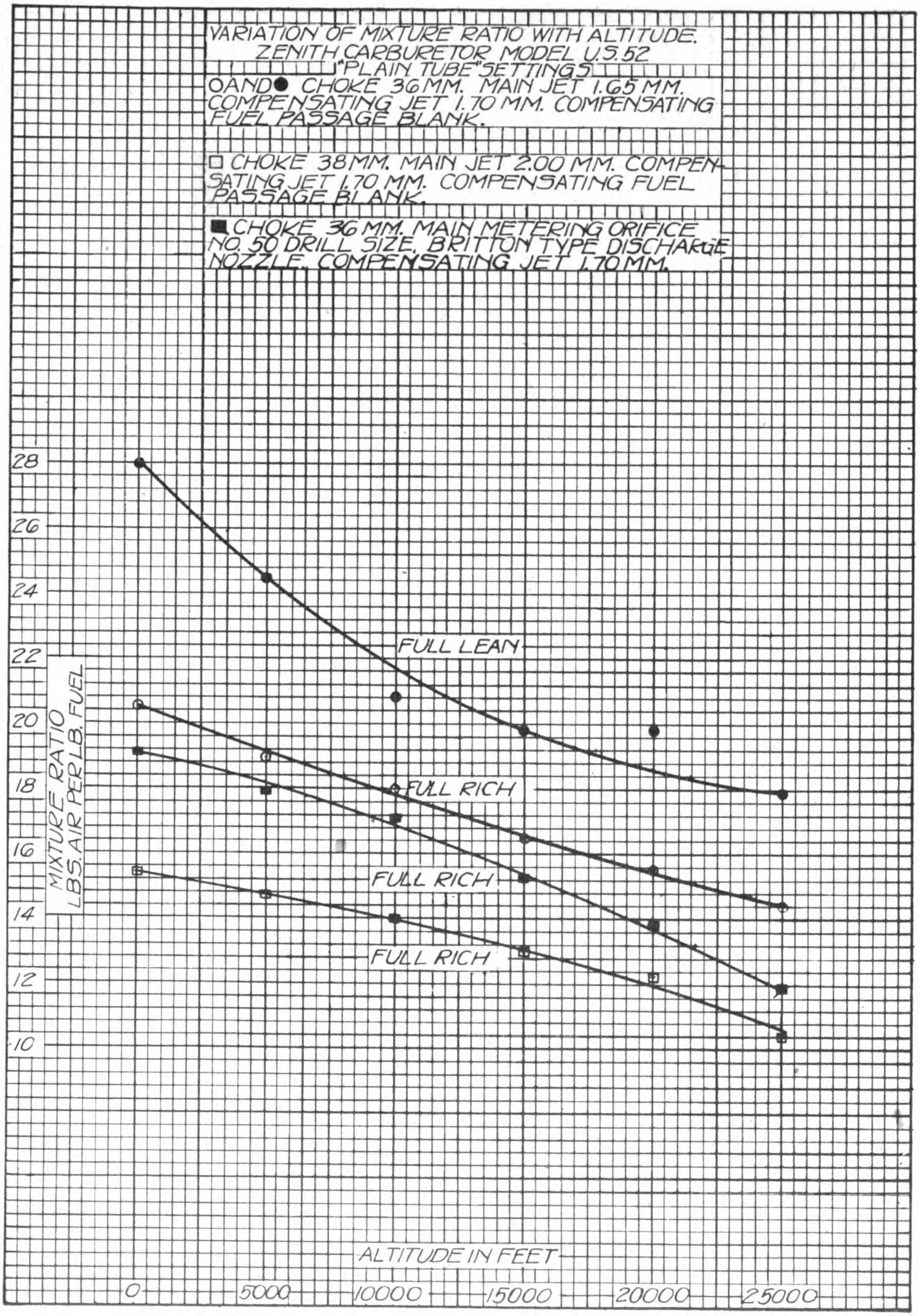

VARIATION OF MIXTURE RATIO WITH ALTITUDE.
ZENITH CARBURETOR MODEL U.S.52
"PLAIN TUBE" SETTINGS
O AND ● CHOKE 36 MM. MAIN JET 1.65 MM. COMPENSATING JET 1.70 MM. COMPENSATING FUEL PASSAGE BLANK.
□ CHOKE 38 MM. MAIN JET 2.00 MM. COMPENSATING JET 1.70 MM. COMPENSATING FUEL PASSAGE BLANK.
■ CHOKE 36 MM. MAIN METERING ORIFICE NO. 50 DRILL SIZE, BRITTON TYPE DISCHARGE NOZZLE. COMPENSATING JET 1.70 MM.
FULL LEAN
FULL RICH
FULL RICH
FULL RICH
MIXTURE RATIO
LBS. AIR PER LB. FUEL
28
26
24
22
20
18
16
14
12
10
ALTITUDE IN FEET
0
5000
10000
15000
20000
25000

FIG. 5.

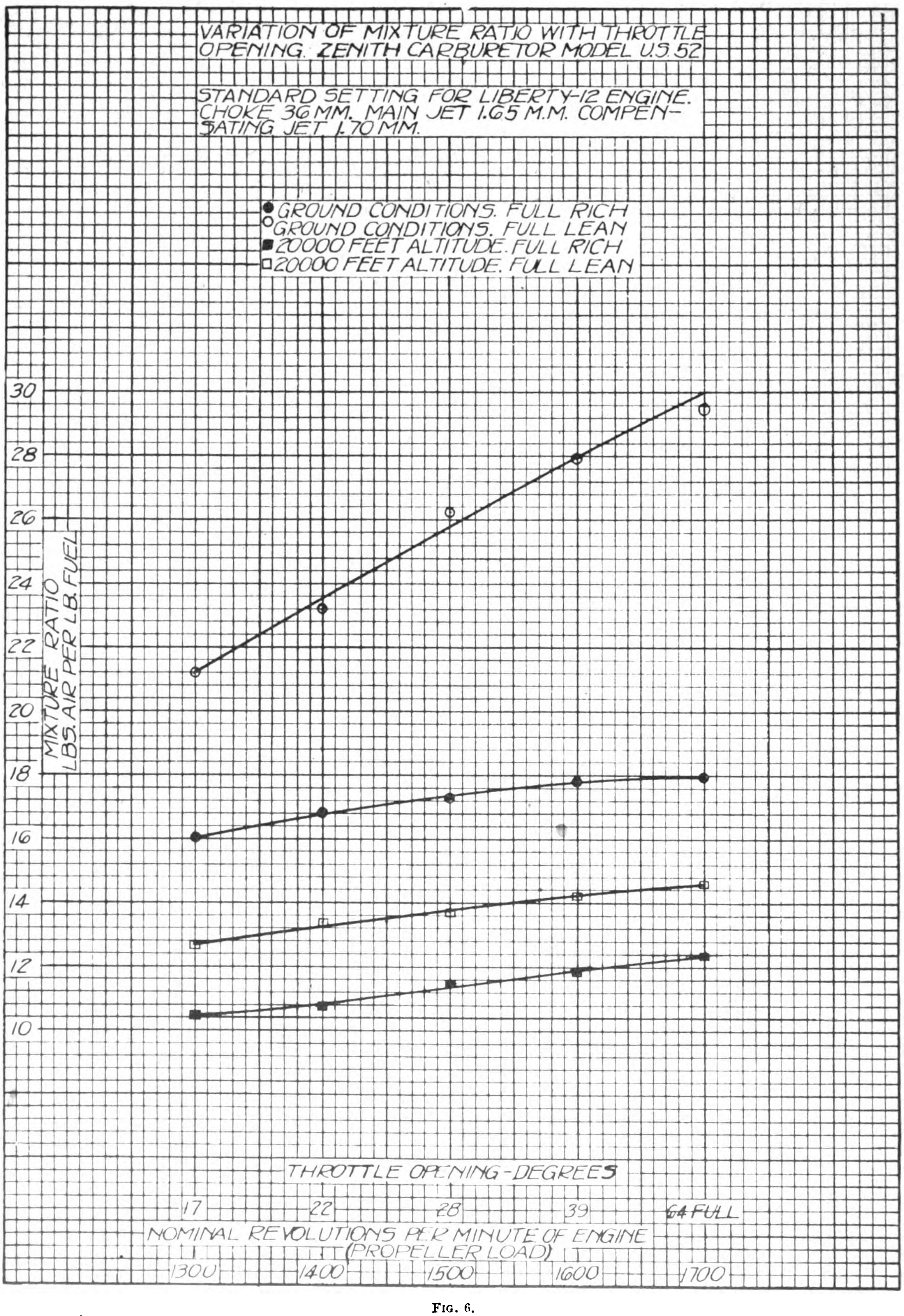

VARIATION OF MIXTURE RATIO WITH THROTTLE OPENING. ZENITH CARBURETOR MODEL U.S. 52
STANDARD SETTING FOR LIBERTY-12 ENGINE. CHOKE 36 MM. MAIN JET 1.65 M.M. COMPENSATING JET 1.70 MM.
GROUND CONDITIONS. FULL RICH
GROUND CONDITIONS. FULL LEAN
20000 FEET ALTITUDE. FULL RICH
20000 FEET ALTITUDE. FULL LEAN
MIXTURE RATIO
LBS. AIR PER LB. FUEL
30
28
26
24
22
20
18
16
14
12
10
THROTTLE OPENING - DEGREES
17
22
28
39
64 FULL
NOMINAL REVOLUTIONS PER MINUTE OF ENGINE
(PROPELLER LOAD)
1300
1400
1500
1600
1700

Fig. 6.

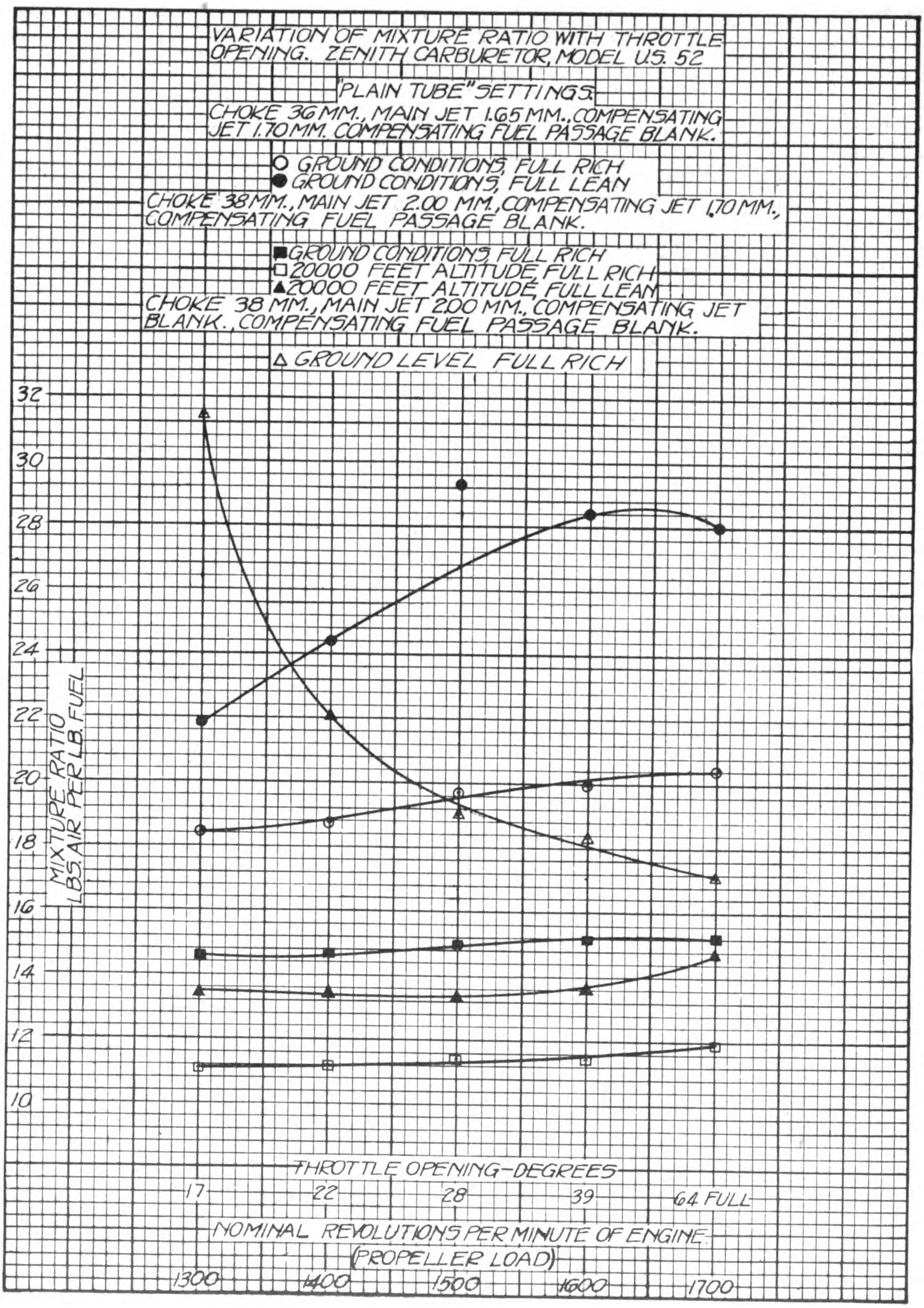

VARIATION OF MIXTURE RATIO WITH THROTTLE OPENING. ZENITH CARBURETOR, MODEL U.S. 52
"PLAIN TUBE" SETTINGS.
CHOKE 36 MM., MAIN JET 1.65 MM., COMPENSATING JET 1.70 MM. COMPENSATING FUEL PASSAGE BLANK.
○ GROUND CONDITIONS, FULL RICH
● GROUND CONDITIONS, FULL LEAN
CHOKE 38 MM., MAIN JET 2.00 MM., COMPENSATING JET 1.70 MM., COMPENSATING FUEL PASSAGE BLANK.
■ GROUND CONDITIONS FULL RICH
□ 20000 FEET ALTITUDE, FULL RICH
▲ 20000 FEET ALTITUDE, FULL LEAN
CHOKE 38 MM., MAIN JET 2.00 MM., COMPENSATING JET BLANK., COMPENSATING FUEL PASSAGE BLANK.
△ GROUND LEVEL FULL RICH
MIXTURE RATIO LBS. AIR PER LB. FUEL
32
30
28
26
24
22
20
18
16
14
12
10
THROTTLE OPENING-DEGREES
17
22
28
39
64 FULL
NOMINAL REVOLUTIONS PER MINUTE OF ENGINE (PROPELLER LOAD)
1300
1400
1500
1600
1700

FIG. 7.

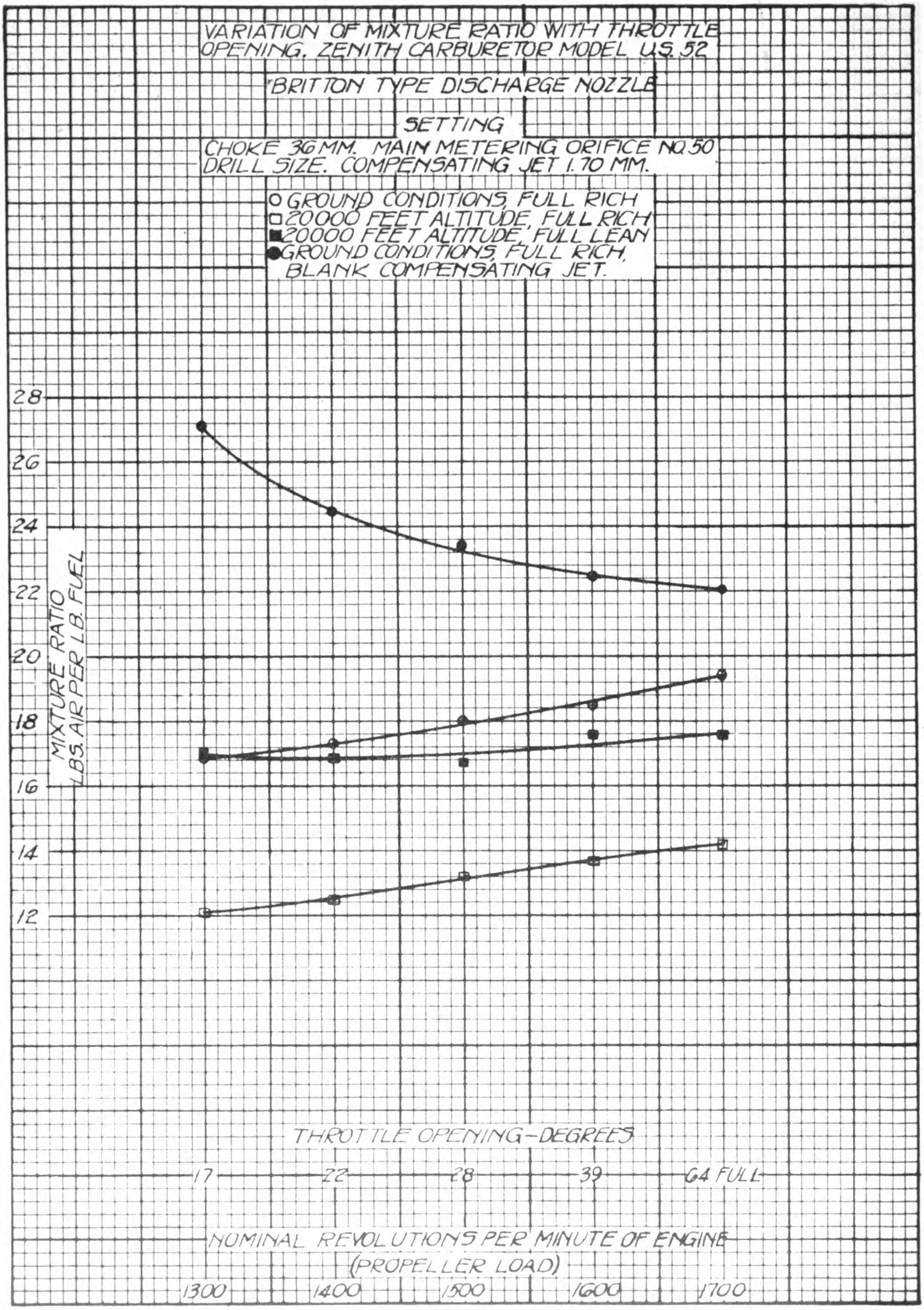

VARIATION OF MIXTURE RATIO WITH THROTTLE OPENING. ZENITH CARBURETOR MODEL U.S. 52
"BRITTON TYPE DISCHARGE NOZZLE
SETTING
CHOKE 36 MM. MAIN METERING ORIFICE NO. 50 DRILL SIZE. COMPENSATING JET 1.70 MM.
GROUND CONDITIONS, FULL RICH
20000 FEET ALTITUDE, FULL RICH
20000 FEET ALTITUDE, FULL LEAN
GROUND CONDITIONS, FULL RICH, BLANK COMPENSATING JET.
MIXTURE RATIO LBS. AIR PER LB. FUEL
28
26
24
22
20
18
16
14
12
THROTTLE OPENING-DEGREES
17
22
28
39
64 FULL
NOMINAL REVOLUTIONS PER MINUTE OF ENGINE
(PROPELLER LOAD)
1300
1400
1500
1600
1700

Fig. 8.

The mixture ratios obtained with each jet separately and with the standard carburetor are shown in Figure 9. The data on the standard carburetor setting plotted on this curve sheet as a basis for comparison are the same as that plotted in Figure 6 but to a different scale. The curve obtained with the compensating jet only, full lean, is discontinued at 1,430 revolutions per minute and a mixture ratio of 90, the slope indicating that at full throttle practically no fuel flows through the compensating jet. This curve is continued to 1,600 revolutions per minute in Figure 10. The effect of the control on the main jet is approximately the same at all speeds on propeller load, the mixture ratio curves being very nearly parallel. The difference in mixture ratio curves, full rich and full lean, of the standard carburetor is, therefore, due to the change of fuel flow through the compensating jet.

The curve showing mixture ratio on propeller load of the idling discharge jet only (see fig. 10) was obtained with the main jet blank and the compensating fuel passage blank. The curve of fuel flow under the same conditions is shown in Figure 11. This does not indicate, however, the quantity which passes through the idling passages of the standard carburetor at full throttle, but checks very closely with the values of fuel flow as obtained by subtracting the flow through the main jet alone from that of the "plain tube" setting. The fuel flow curves in Figure 11 are plotted from the same data as the mixture ratio curves in Figures 9 and 10.

The fuel flow, with the control in the full lean position, is shown for various jet combinations in Figure 12. The use of the control brings the fuel-flow curves of the standard and the "plain tube" settings together over the full propeller load range, and reduces the flow through the compensating jet to practically zero at 1,700 revolutions per minute.

The effect of float-chamber vacuum on mixture ratio at various altitudes is shown by the curves in Figure 13. These curves indicate the characteristics of the back-suction type of control as applied to a carburetor using a gravity flow compensator jet.

The curve in Figure 14, variation of mixture ratio with air flow, shows the ratios corresponding to full throttle operation.

The flight tests made with the "plain tube" setting on a Liberty "6" engine in airplane P-173 and on a Liberty "12" engine in airplane P-175 indicate the "plain tube" setting to be equal in performance to the standard setting both as to load and altimetric compensation characteristics.

Liberty "6" engine—Standard Zenith carburetor, model U. S. 52.

FULL POWER RUN.

R. P. M.	Actual.		Corrected.			Water.		Oil.			Carb. air temp. °F.	Man. vac. in. hg.	Fuel cons.		Float chamber vac. in. H_2O.	Position [1] of alt. control.
	Brake load lb.	B.H.P.	Torque lb. ft.	H. P.	B. M. E. P. lb. per sq. in.	Temp. °F.		Temp. °F.		Press. lb. per sq. in.			Sec. for 3-lbs.	Lb. per hp. hr.		
						In.	Out.	In.	Out.							
1,200	383	153.2	682	156.0	124.7	148	162	74	102	25	54	1.1	148	0.477	....	5.5
1,310	376	165.0	674	168.0	123.4	150	170	80	110	26	58	1.3	....	....	4.6	5.45
1,420	380	180.0	678	183.2	124.0	150	170	90	118	26	54	1.5	124	.484	4.2	6.25
1,510	378	190.2	674	193.6	123.4	152	172	92	110	26	56	1.6	....	....	4.5	6.60
1,620	368	198.7	656	202.2	120.0	152	172	94	108	26	58	1.8	111	.489	5.4	6.45
1,730	352	203.0	628	206.6	114.9	152	170	100	108	26	58	1.9	....	....	5.8	6.85
1,790	319	190.2	568	193.6	104.0	152	170	106	116	26	....	2.0	98	.579	6.6	7.25
1,890	294	185.2	524	188.5	95.8	148	168	106	122	27	56	2.2	....	....	7.2	7.25
2,010	249	166.8	444	169.8	81.2	154	174	106	130	27	56	2.2	97	.668	7.8	7.25

PROPELLER LOAD RUN.

R. P. M.	Actual.		Corrected.		Water.		Oil.			Carb. air temp. °F.	Man. vac. in. hg.	Fuel cons.		Carb. float cham. in. H_2O.	Position [1] of alt. control.
	Brake load lb.	B.H.P.	Torque lb. ft.	H. P.	Temp. °F.		Temp. °F.		Press. lb. per sq. in.			Sec. for 3 lbs.	Lb. per hp. hr.		
					In.	Out.	In.	Out.							
1,710	356	203.0	634	206.8	152	170	111	110	28	56	1.4	106	0.502	6.0	6.50
1,630	309	168.0	551	171.0	152	168	110	108	28	56	3.2	138	.466	4.2	6.50
1,500	272	136.0	484	138.5	154	168	106	100	27	58	3.9	[2] 112	.473	3.2	6.50
1,440	240	115.2	430	117.3	156	170	102	104	26	58	4.6	[2] 126	.496	2.8	6.50
1,290	204	87.7	363	89.3	156	168	102	116	26	....	7.7	[2] 165	.498	2.2	6.50
1,200	174	69.6	310	70.9	154	170	102	120	25	58	9.7	[2] 198	.522	2.0	6.50

Data for both runs:
- Length of brake arm, 21 inches.
- Average barometer, 29.40 in. hg.
- Kind of oil used, U. S. Spec. No. 3501—Viscosity of oil, 115-125 at 210 °F.

Kind of fuel used, aviation gasoline, W. D. Spec. No. 2-40.
Specific gravity of fuel, 0.707 at 60° F.
Carburetor setting: Choke, 36 mm.; main jet, 1.65 mm.; comp. jet, 1.70 mm.

[1] Mixture control setting: F. R., 7.75; F. L., 0.

[2] Two pounds fuel.

Date of run: February 12, 1921.

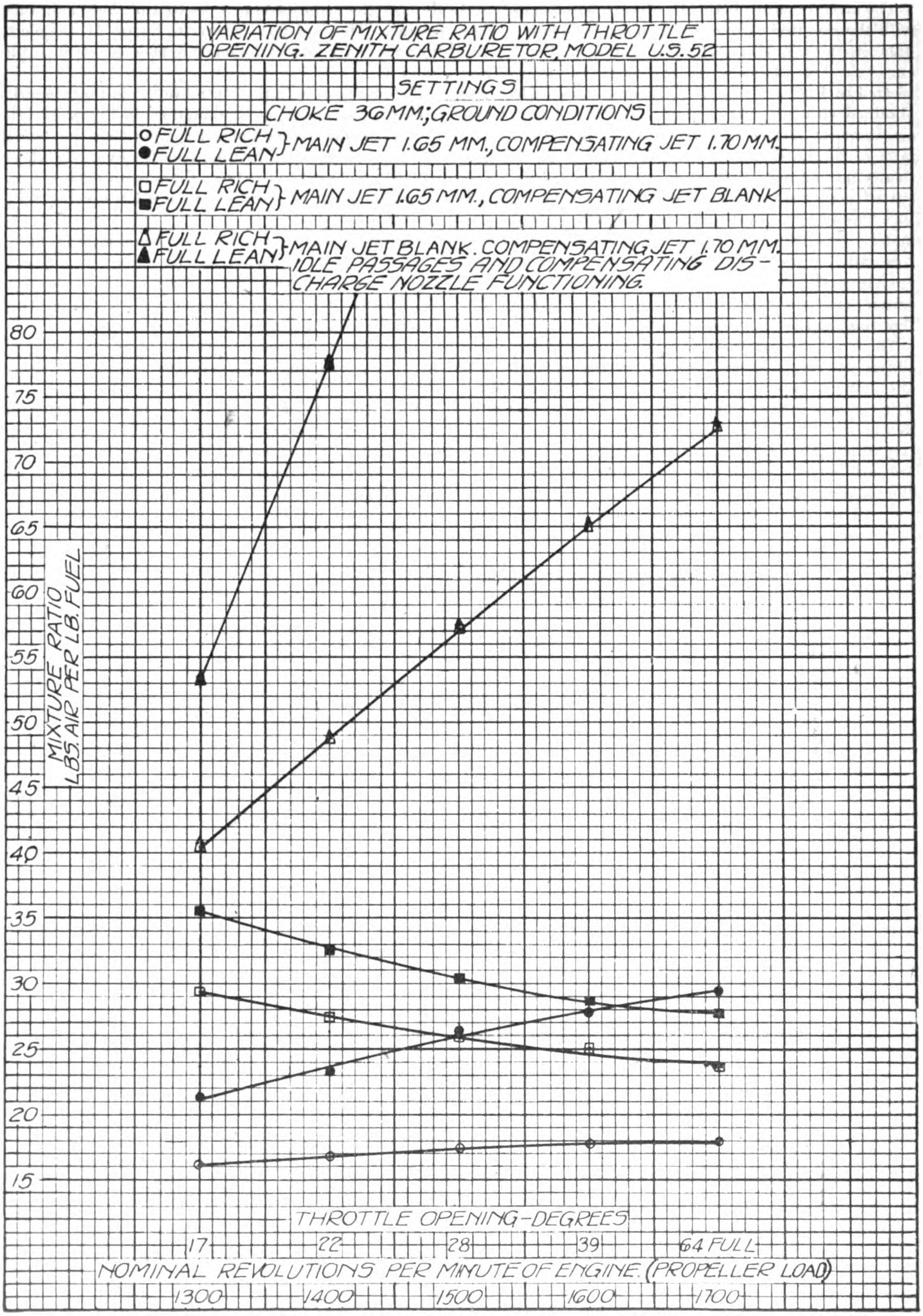

VARIATION OF MIXTURE RATIO WITH THROTTLE OPENING. ZENITH CARBURETOR, MODEL U.S. 52
SETTINGS
CHOKE 36 MM.; GROUND CONDITIONS
○ FULL RICH
● FULL LEAN } MAIN JET 1.65 MM., COMPENSATING JET 1.70 MM.
□ FULL RICH
■ FULL LEAN } MAIN JET 1.65 MM., COMPENSATING JET BLANK
△ FULL RICH
▲ FULL LEAN } MAIN JET BLANK. COMPENSATING JET 1.70 MM. IDLE PASSAGES AND COMPENSATING DISCHARGE NOZZLE FUNCTIONING.
MIXTURE RATIO LBS. AIR PER LB. FUEL
80
75
70
65
60
55
50
45
40
35
30
25
20
15
THROTTLE OPENING-DEGREES
17
22
28
39
64 FULL
NOMINAL REVOLUTIONS PER MINUTE OF ENGINE. (PROPELLER LOAD)
1300
1400
1500
1600
1700

FIG. 9.

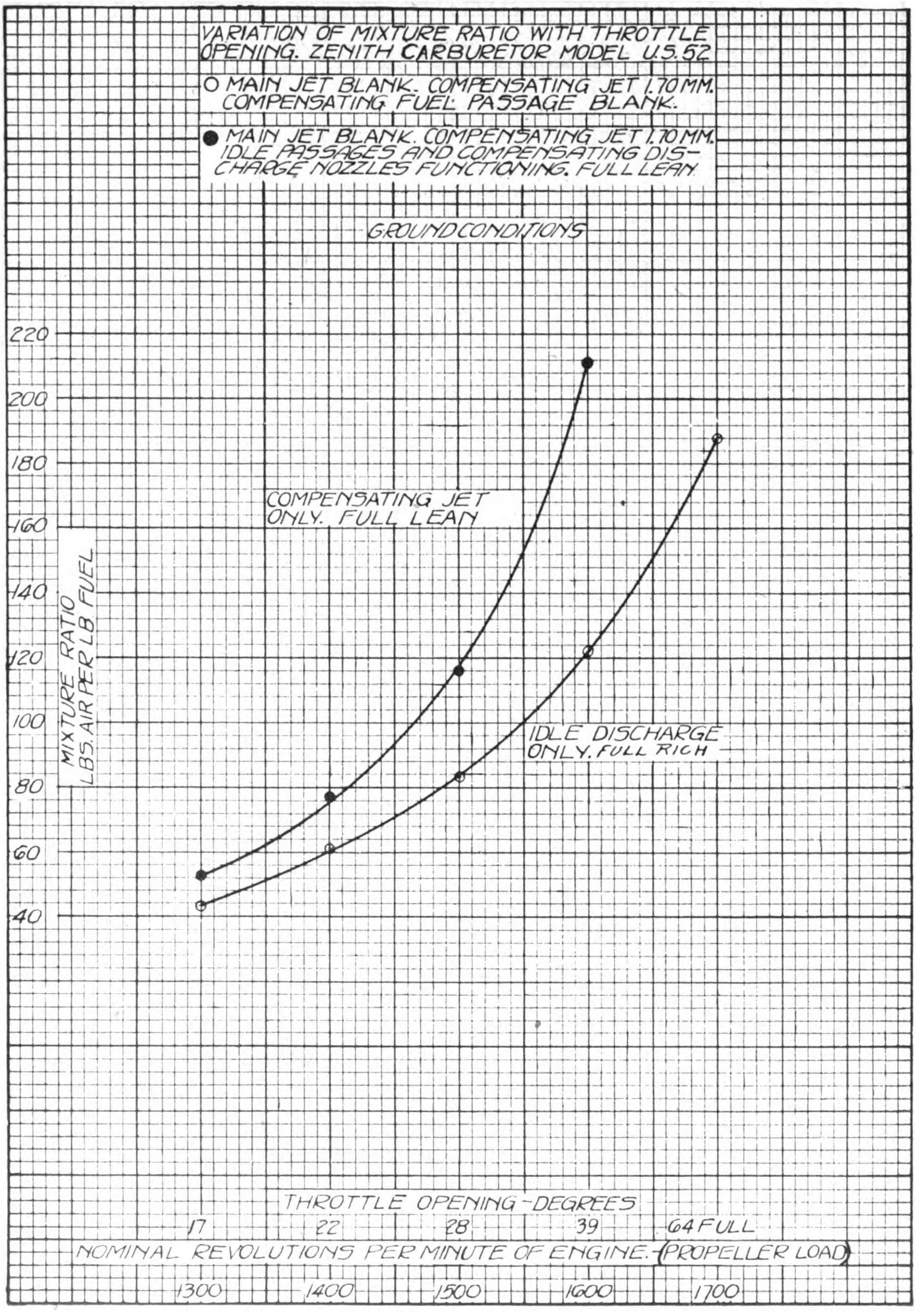

VARIATION OF MIXTURE RATIO WITH THROTTLE OPENING. ZENITH CARBURETOR MODEL U.S.52
O MAIN JET BLANK. COMPENSATING JET 1.70 MM. COMPENSATING FUEL PASSAGE BLANK.
● MAIN JET BLANK. COMPENSATING JET 1.70 MM. IDLE PASSAGES AND COMPENSATING DISCHARGE NOZZLES FUNCTIONING. FULL LEAN.
GROUND CONDITIONS
COMPENSATING JET ONLY. FULL LEAN
IDLE DISCHARGE ONLY. FULL RICH
MIXTURE RATIO LBS. AIR PER LB. FUEL
220
200
180
160
140
120
100
80
60
40
THROTTLE OPENING - DEGREES
17
22
28
39
64 FULL
NOMINAL REVOLUTIONS PER MINUTE OF ENGINE. - (PROPELLER LOAD)
1300
1400
1500
1600
1700

Fig. 10.

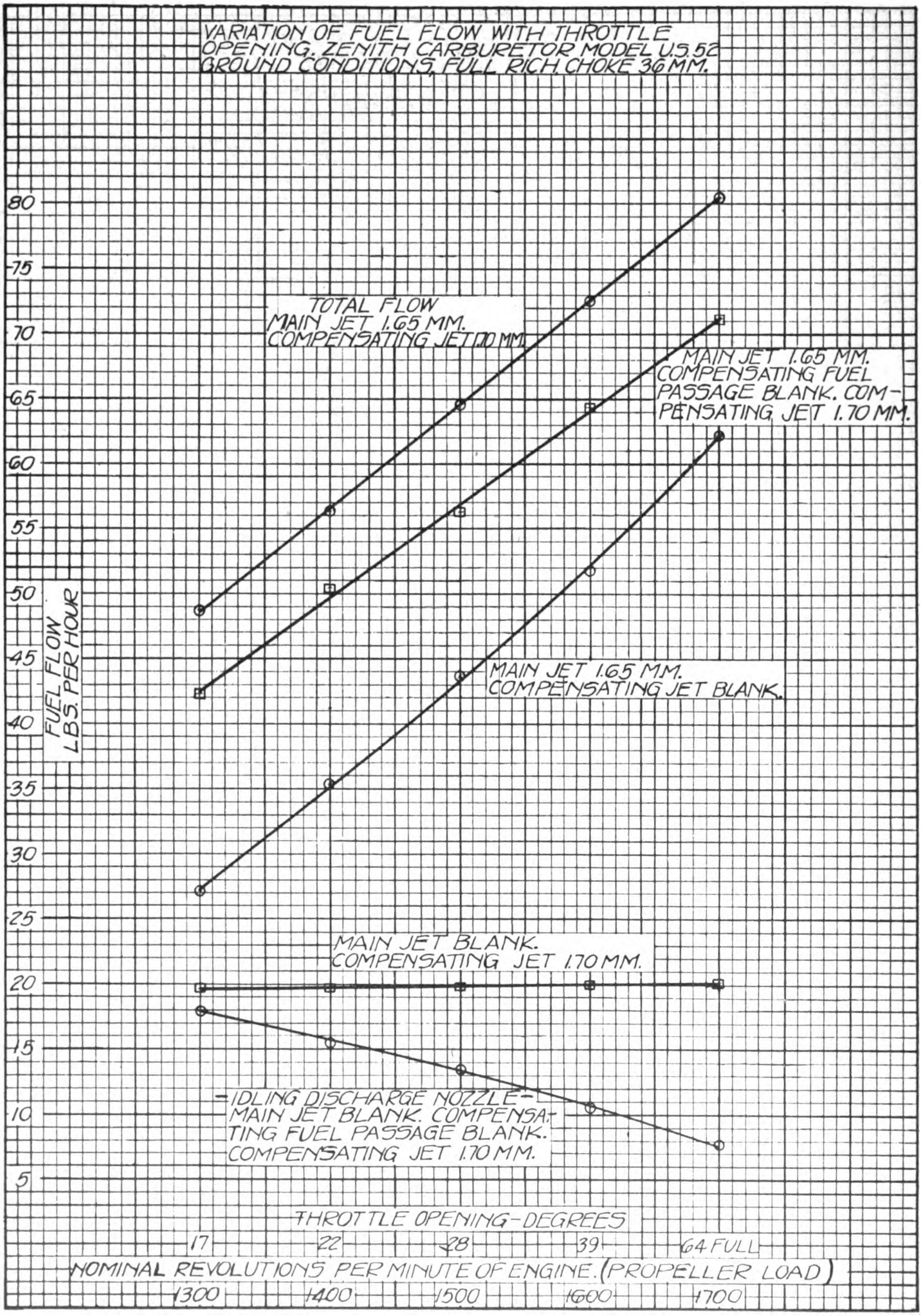

VARIATION OF FUEL FLOW WITH THROTTLE OPENING. ZENITH CARBURETOR MODEL U.S.52 GROUND CONDITIONS. FULL RICH. CHOKE 36 MM.
TOTAL FLOW MAIN JET 1.65 MM. COMPENSATING JET 1.70 MM.
MAIN JET 1.65 MM. COMPENSATING FUEL PASSAGE BLANK. COMPENSATING JET 1.70 MM.
MAIN JET 1.65 MM. COMPENSATING JET BLANK.
MAIN JET BLANK. COMPENSATING JET 1.70 MM.
IDLING DISCHARGE NOZZLE-MAIN JET BLANK. COMPENSATING FUEL PASSAGE BLANK. COMPENSATING JET 1.70 MM.
FUEL FLOW LBS. PER HOUR
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
THROTTLE OPENING-DEGREES
17
22
28
39
64 FULL
NOMINAL REVOLUTIONS PER MINUTE OF ENGINE. (PROPELLER LOAD)
1300
1400
1500
1600
1700

Fig. 11.

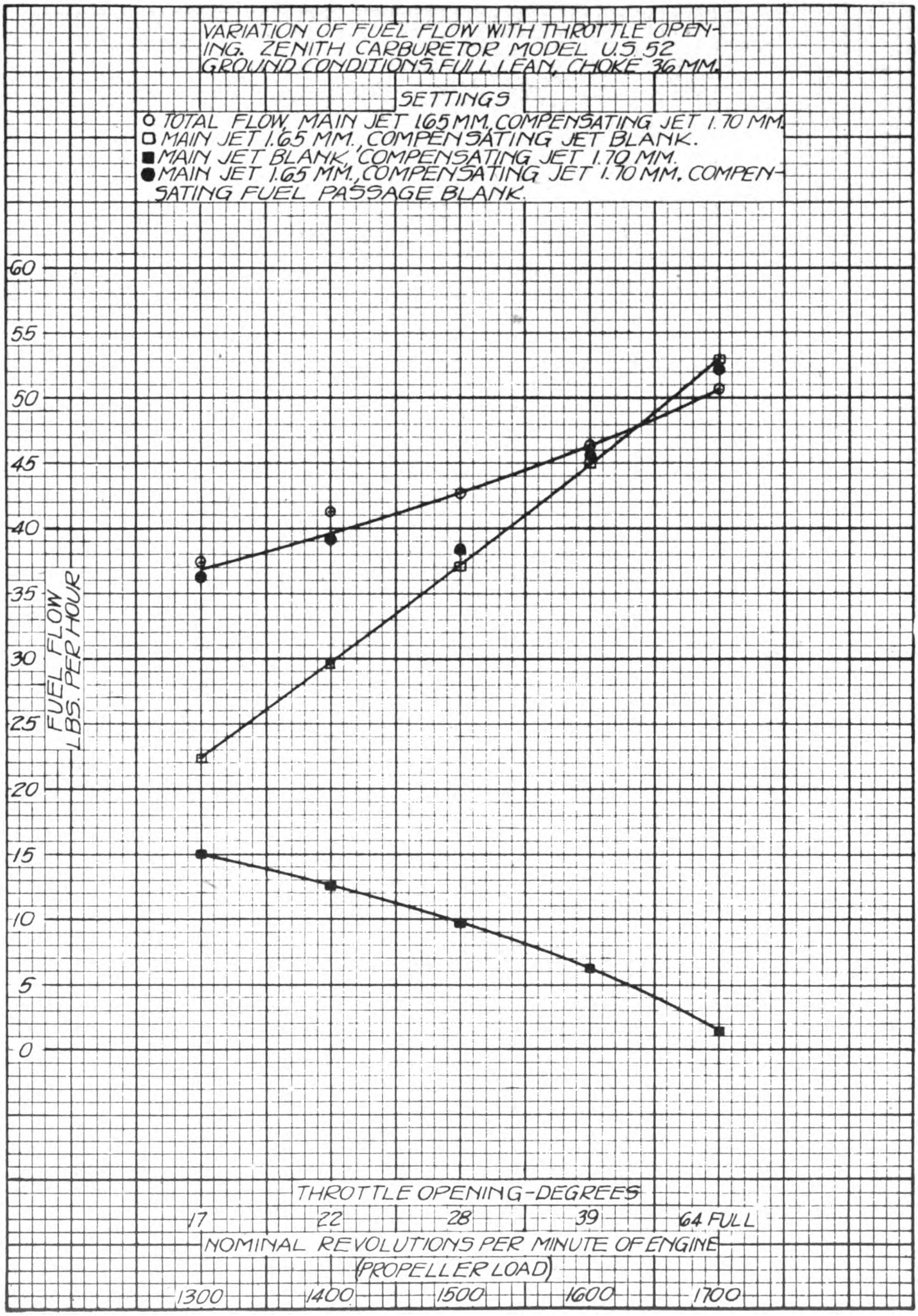

VARIATION OF FUEL FLOW WITH THROTTLE OPENING. ZENITH CARBURETOR MODEL U.S. 52
GROUND CONDITIONS, FULL LEAN, CHOKE 36 MM.
SETTINGS
○ TOTAL FLOW, MAIN JET 1.65 MM, COMPENSATING JET 1.70 MM.
□ MAIN JET 1.65 MM. COMPENSATING JET BLANK.
■ MAIN JET BLANK, COMPENSATING JET 1.70 MM.
● MAIN JET 1.65 MM., COMPENSATING JET 1.70 MM. COMPENSATING FUEL PASSAGE BLANK.
FUEL FLOW LBS. PER HOUR
60
55
50
45
40
35
30
25
20
15
10
5
0
THROTTLE OPENING-DEGREES
17
22
28
39
64 FULL
NOMINAL REVOLUTIONS PER MINUTE OF ENGINE
(PROPELLER LOAD)
1300
1400
1500
1600
1700

FIG. 12.

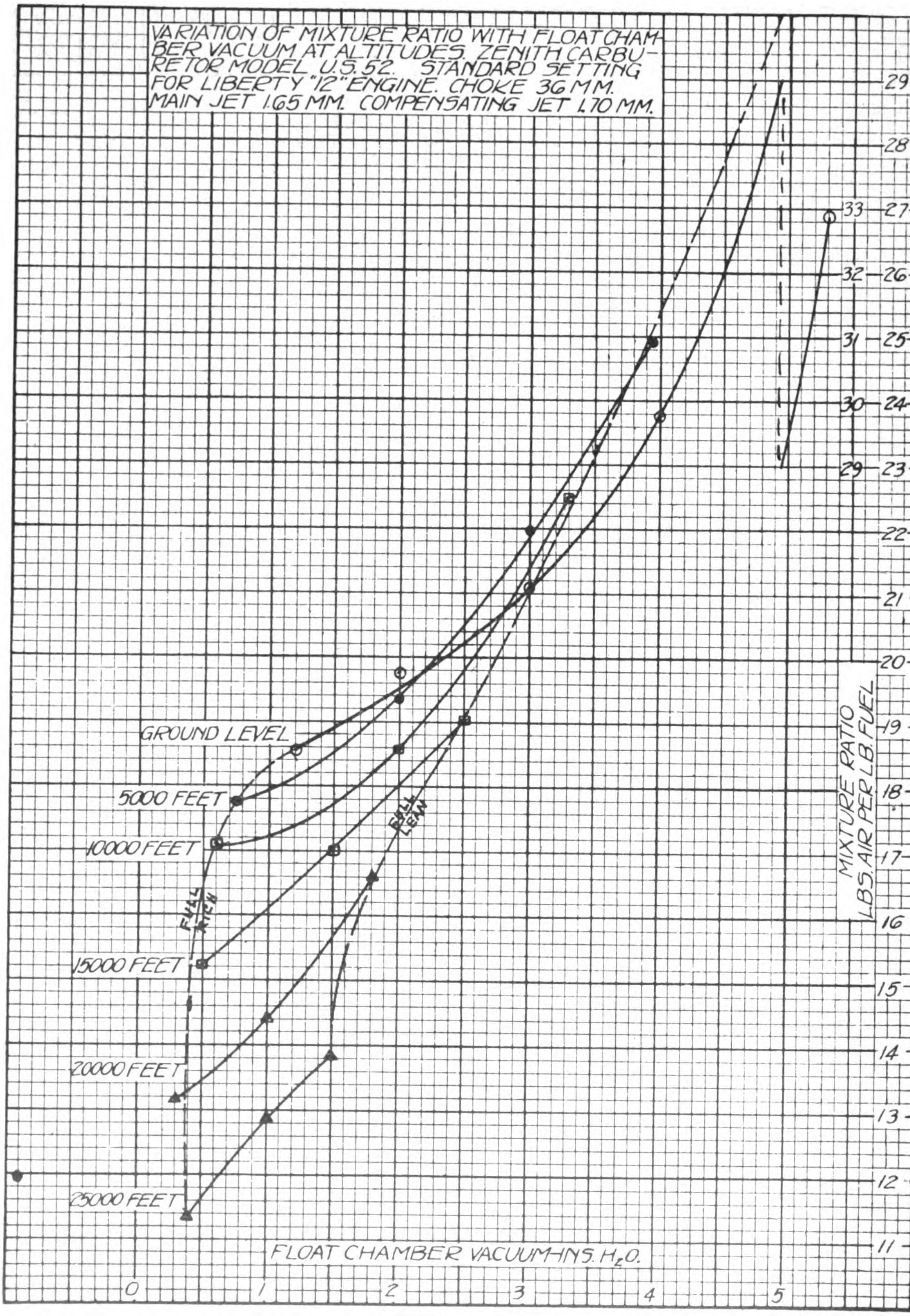

VARIATION OF MIXTURE RATIO WITH FLOAT CHAMBER VACUUM AT ALTITUDES. ZENITH CARBURETOR MODEL U.S. 52. STANDARD SETTING FOR LIBERTY "12" ENGINE. CHOKE 36 MM. MAIN JET 1.65 MM. COMPENSATING JET 1.70 MM.
GROUND LEVEL
5000 FEET
10000 FEET
15000 FEET
20000 FEET
25000 FEET
FULL RICH
FULL LEAN
MIXTURE RATIO
LBS. AIR PER LB. FUEL
FLOAT CHAMBER VACUUM-INS. H_2O.
0
1
2
3
4
5
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
29
30
31
32
33

FIG. 13.

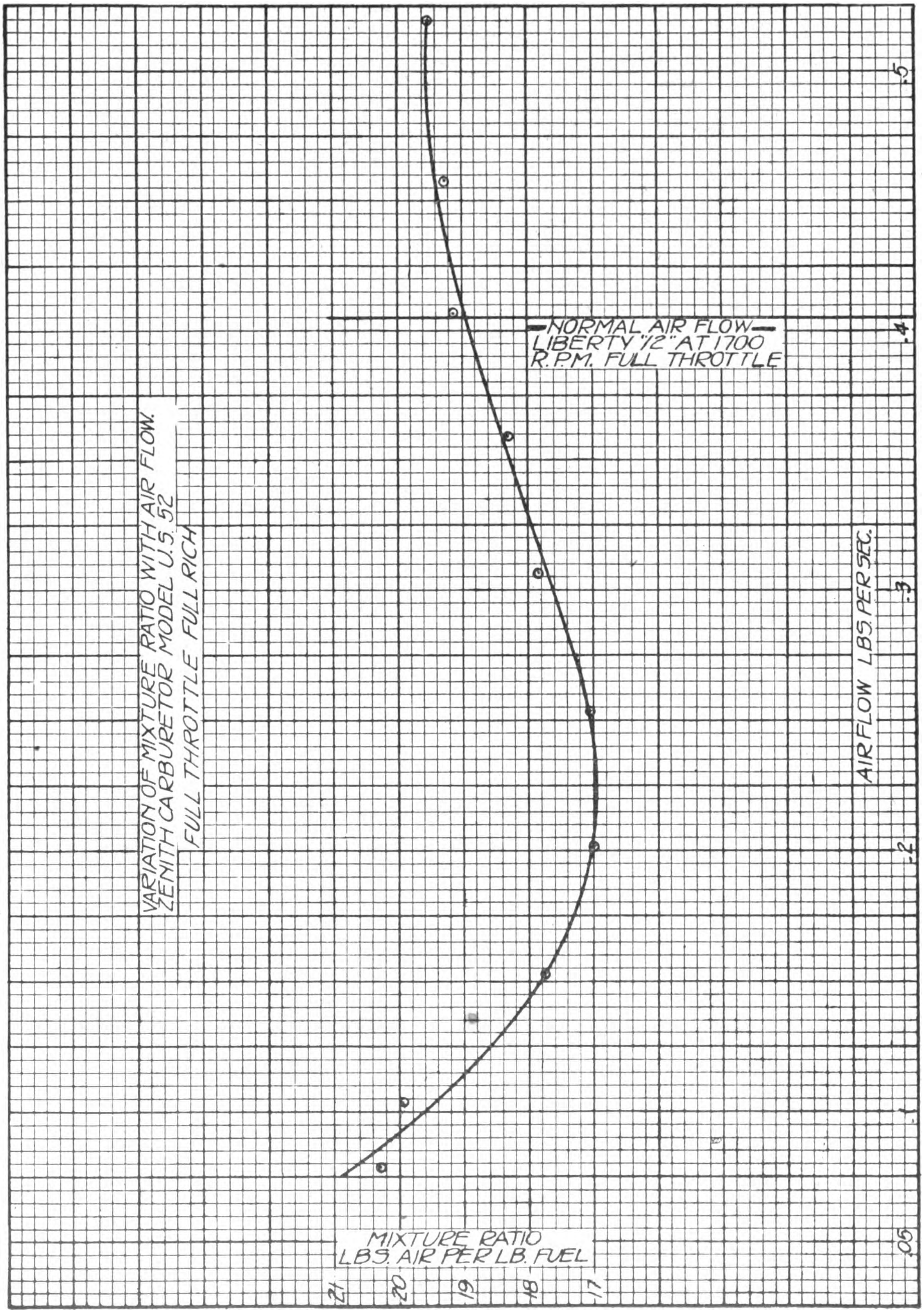

VARIATION OF MIXTURE RATIO WITH AIR FLOW.
ZENITH CARBURETOR MODEL U.S. 52
FULL THROTTLE FULL RICH
NORMAL AIR FLOW
LIBERTY "12" AT 1700
R.P.M. FULL THROTTLE
AIR FLOW LBS. PER SEC.
.05
.1
.2
.3
.4
.5
MIXTURE RATIO
LBS. AIR PER LB. FUEL
21
20
19
18
17

FIG. 14

Liberty "12" aviation engine—Five minute fuel consumption runs on torque stand—Zenith U. S. 52 carburetor.

STANDARD SETTING.

R. P. M.	Actual.		Corrected H. P.	Man. vac. in. hg.	Float chamber vac. in. H_2O.		Mixture control position.	Fuel cons.	
	Brake load lb.	B. H. P.			Prop. end.	Gear end.		Lb./hr.	Lb./hp/hr.
1,692	294	382.5	393.2	1.7	10.3	9.1	F. R.	217.2	0.568
1,696	297	387.8	398.5	1.8	11.9	9.9	Best	204.0	.526
1,506	220	255.0	262.0	4.5	6.4	5.7	F. R.	121.2	.475
1,488	215	246.0	253.0	4.4	6.5	5.8	Best	118.8	.483
1,294	167	166.2	171.0	9.6	2.6	2.4	F. R.	78.0	.469
1,272	159	155.5	160.0	9.3	3.5	2.6	Best	78.0	.501
1,034	105	83.5	85.8	14.4	1.4	1.1	F. R.	48.0	.575
966	98	72.8	74.8	14.0	1.0	1.2	F. L.	45.6	.626

NOTE.—Engine operation rough at 1,000 R. P. M. settings.

Length of brake arms, 48.5 in.
Fuel used (Spec. grav.), 0.710 at 60° F., W. D. Spec. 2-40.
Barometer, 29.10 in. hg.
Oil used, U. S. Spec. No. 3501, viscosity, 115-125 at 210 ° F.
March 24, 1922.

Average air temp., 70° F.
Outlet water temp., 170° F.
Carburetor settings: Carburetor used, Zenith U. S. 52; Chokes, 36 mm.; Main jets, 1.65 mm.; Comp. jets, 1.70 mm.

Liberty "6" engine—Zenith carburetor, model U. S. 52, "plain tube" arrangement, compensating fuel passage blank.

FULL-POWER RUNS.

R. P. M.	Actual.		Corrected.			Water.		Oil.			Carb. air temp. °F.	Man. vac. in. hg.	Fuel cons.		Float chamber vac. in. H_2O.	Position[1] of alt. control.
	Brake load lb.	B.H.P.	Torque lb. ft.	H. P.	B. M. E. P. lb. per sq. in.	Temp. °F.		Temp. °F.		Press. lb. per sq. in.			Sec. for 3 lbs.	Lb. per hp.-hr.		
						In.	Out.	In.	Out.							
1,310	368	160.7	664	165.7	121.5	152	172	92	100	25	72	1.2	125	0.537	5.4	0.75
1,530	369	188.2	666	194.0	121.9	154	172	98	100	26	72	1.5	108	.532	5.8	4.50
1,700	344	195.0	620	201.0	113.4	156	174	100	108	26	73	1.7	106	.525	7.0	5.00
1,930	270	173.8	467	179.2	89.1	152	168	102	122	27	72	1.9	121	.514	8.3	5.25
2,010	254	170.2	459	175.5	84.0	152	172	108	120	28	72	2.0	113	.561	8.3	5.50

Carburetor setting: Chokes, 38 mm.; main jet, 2.00 mm.; comp. jet, 1.70 mm. Barometer: 29.02 in. hg. February 15, 1921.

1,300	380	164.6	682	168.5	124.7	152	172	122	134	27	60	1.2	139	0.472	3.6	5.75
1,600	368	196.2	658	200.8	120.4	152	171	124	144	28	60	1.6	120	.459	5.2	6.00
1,910	300	191.0	538	195.4	98.4	154	172	122	130	28	60	1.8	103	.549	7.4	6.25

Carburetor setting: Chokes, 36 mm.; main jet, 1.65 mm.; comp. jet, 1.70 mm. Barometer: 29.28 in. hg.
Data for both runs: Length of brake arm, 21 in.; kind of oil used, U. S. Spec. No. 3501; viscosity 115–125 at 210° F.; kind of fuel used, aviation gasoline, W. D. Spec. 2–40; specific gravity, 0.707 at 60° F. March 3, 1921.
[1] Mixture control setting: F. R., 7.5; F. L., 0.75.

PROPELLER-LOAD RUNS.

R. P. M.	Actual.		Corrected.		Water.		Oil.			Carb. air temp. °F.	Man. vac. in. hg.	Fuel cons.		Float chamber vac. in. H_2O.	Position[1] of alt. control.
	Brake load lb.	B.H.P.	Torque lb. ft.	H. P.	Temp. °F.		Temp. °F.		Press. lb. per sq. in.			Sec. for 3 lbs.	Lb. per hp.-hr.		
					In.	Out.	In.	Out.							
1,730	342	197.4	618	203.4	152	168	108	116	28	....	1.8	112	0.489	7.0	5.0
1,620	302	163.0	544	168.0	154	169	110	112	27	72	3.7	140	.473	4.2	5.0
1,510	266	133.9	480	138.0	154	168	114	112	27	73	5.5	[2] 119	.452	3.0	5.0
1,400	230	107.4	415	110.7	156	170	112	110	26	72	7.6	[2] 141	.476	2.5	5.0
1,310	199	86.9	358	89.6	156	170	110	106	26	72	9.6	[2] 167	.496	2.0	5.0
1,210	168	67.8	200	69.9	158	172	106	101	25	72	10.7	[2] 208	.510	1.6	5.0

Carburetor setting: Chokes, 38 mm.; main jet, 2.00 mm.; comp. jet, 1.70 mm. Barometer: 29.02 in. hg. February 15, 1921.

1,710	351	200.0	628	204.6	152	170	122	126	28	58	1.7	[2,4] 110	0.491	6.2	6.00
1,520	273	138.4	489	141.5	152	168	122	120	28	60	3.8	[2,4] 103	.504	2.8	6.00
1,300	204	88.4	365	90.4	158	174	118	112	26	60	6.3	[4] 80	.509	2.2	6.00
1,220	178	72.4	319	74.0	156	168	116	108	26	60	8.4	[4] 94	.529	1.8	6.00

Carburetor setting: Chokes, 36 mm.; main jet, 1.65 mm.; comp. jet, 1.70 mm. Barometer: 29.28 in. hg. March 3, 1921.
Data for all runs: Length of brake arm, 21 in.; kind of oil used, U. S. Spec. No. 3501; viscosity, 115–125 at 210° F.; kind of fuel used, aviation gasoline, W. D. Spec. No. 2–40; specific gravity of fuel, 0.707 at 60° F.
[1] Mixture control setting: F. R., 7.50; F. L., 0.75.
[2] 2 pounds fuel.
[3] 3 pounds fuel.
[4] Sec. 1 lb.

Liberty "12" aviation engine—five-minute fuel-consumption runs on torque stand—Zenith U. S. 52 carburetor.

"PLAIN TUBE" SETTING.

R. P. M.	Actual.		Corrected H. P.	Man. vac. in. hg.	Float chamber vac. in. H_2O.		Mixture control position.	Fuel cons.	
	Brake load, lb.	B. H. P.			Prop. end.	Gear end.		Lb./hr.	Lb./hp./hr.
1,676	312.0	402.0	410.0	1.7	9.1	7.8	F. R.	209.0	0.520
1,670	307.0	394.0	402.0	1.7	10.7	8.4	Best	198.0	.503
1,488	235.0	269.0	274.0	4.4	4.9	4.3	F. R	126.0	.468
1,494	231.5	266.0	271.0	4.3	5.1	4.4	Best	129.6	.487
1,284	172.0	170.0	173.4	10.0	2.3	1.5	F. R	85.2	.501
1,278	170.0	167.0	170.3	10.0	2.3	2.1	Best	84.0	.503
1,066	112.0	91.8	93.6	14.0	1.1	1.1	F. R	54.0	.588
1,030	107.5	85.2	86.9	15.1	1.1	1.1	Best	48.0	.563

Length of brake arm, 48.5 in.; fuel used (spec. grav.), 0.710 at 60° F., W. D. Spec. 2-40; barometer, 29.35 in. hg.; oil used, U. S. Spec. No. 3501, viscosity 115-125 at 210° F., average air temp., 40° F.; outlet water temp., 170° F.

Carburetor settings: Carburetor used, Zenith U. S. 52; chokes, 36; main jets, 1.65 mm., comp. jets, 1.70 mm. compensating fuel passage blank. March 22, 1922.

Liberty "6" engine—Zenith carburetor, Model U. S. 52, Britton type discharge nozzles.

FULL POWER RUNS.

R P.M.	Actual.		Corrected.			Water.		Oil.			Carb. air temp. ° F.	Man. vac. in. hg.	Fuel cons.		Float chamber vac. in H_2O.	Position[1] of alt. control.
	Brake load, lb.	B.H.P.	Torque, lb. ft.	H. P.	B. M. E. P. lb. per sq. in.	Temp. ° F. In.	Temp. ° F. Out.	Temp. ° F. In.	Temp. ° F. Out.	Press. lb. per sq. in.			Sec. for 3 lb.	Lb. per hp. hr.		
1,310	369	161.0	662	165.0	121.1	152	171	93	112	25	56	1.5	144	0.466	2.8	6.75
1,530	354	180.5	636	185.0	116.4	154	170	96	106	26	56	2.0	132	.453	3.5	6.75
1,720	329	188.5	590	193.2	108.0	153	172	102	112	26	60	2.4	118	.486	4.4	6.80
1,910	270	172.0	485	176.4	88.8	160	178	102	118	26	60	2.8	111	.566	5.0	7.75
2,030	246	166.5	441	170.6	80.7	148	165	103	132	26	60	2.8	110	.590	5.0	7.50

Carburetor setting: Chokes, 36 mm.; main jet, No. 50 drill size; comp. jet, 1.70 mm. Barometer, 29.20 in. hg. February 14, 1921.

1,300	374	162.0	672	166.4	123.0	152	170	90	92	25	58	1.4	146	0.456	3.0	6.25
1,520	367	186.0	659	191.0	120.5	158	174	92	106	26	59	1.8	125	.464	3.6	6.60
1,730	339	195.5	610	200.8	111.5	154	172	102	142	27	62	2.2	117	.472	5.2	6.25
1,930	281	180.7	505	185.5	92.4	156	173	116	130	27	66	2.5	106	.564	6.0	6.50
2,020	249	167.6	448	172.1	82.0	152	170	116	138	27	....	2.5	106	.608	6.4	....

[1] Mixture control setting: F. R., 7.5; F. L., 0.

Carburetor setting: Chokes, 38 mm.; main jet, No. 47 drill size; comp. jet, 1.70 mm. Barometer, 29.15 in. hg. February 15, 1921.

Data for both runs: Length of brake arm: 21 inches. Kind of oil used: U. S. Spec. No. 3501, viscosity 115-125 at 210° F. Kind of fuel used: aviation gasoline W. D. Spec. 2-40; specific gravity, 0.707 at 60° F.

PROPELLER LOAD RUNS.

R. P. M.	Actual.		Corrected.		Water.		Oil.			Carb. air temp. °F.	Man. vac. in. hg.	Fuel cons.		Float chamber vac. in. H_2O.	Positions[1] of alt. control.
	Brake load lb.	B. H. P.	Torque lb. ft.	H. P.	Temp. °F. In.	Temp. °F. Out.	Temp. °F. In.	Temp. °F. Out.	Press. lb. per sq. in.			Sec. for 3 lb.	Lb. per hp. hr.		
1,740	330	191.5	588	195.0	156	172	96	122	27	63.0	2.5	113	0.499	4.4	6.9
1,620	290	156.6	517	159.5	154	170	100	112	26	64.0	3.8	146	.472	2.4	6.9
1,510	258	129.9	460	132.2	154	173	110	120	26	65.0	5.6	[2] 120	.462	1.8	6.9
1,410	225	105.8	401	107.7	156	170	118	150	26	66.0	8.0	[2] 143	.476	1.5	6.9
1,310	193	84.3	344	85.8	157	170	122	132	26	66.0	10.0	[2] 177	.483	1.4	6.9
1,190	158	62.7	282	63.8	158	171	124	120	25	66.0	11.3	[2] 218	.527	1.3	6.9

Carburetor setting: Choke, 36 mm.; main jet, No. 50 drill size; comp. jet, 1.70 mm. Barometer, 29.40 in. hg. February 14, 1921.

1,710	339	193.2	610	198.4	154	171	112	120	27	64	2.2	117	0.478	5.2	6.30
1,630	302	164.1	542	168.5	153	170	112	114	25	65	3.4	141	.466	3.4	6.30
1,520	266	134.8	478	138.5	154	170	112	108	25	....	4.6	[2] 115	.465	2.4	6.30
1,410	233	109.5	419	112.5	156	168	108	102	25	66	6.6	[2] 139	.473	2.0	6.30
1,310	200	87.4	359	89.8	158	173	106	102	25	66	8.1	[2] 169	.488	1.8	6.30
1,200	170	68.0	306	69.8	156	170	102	92	25	66	9.5	[2] 201	.527	1.5	6.30

[1] Mixture control settings: F. R., 7.75; F. L., 0.
[2] 2 pounds fuel.

Carburetor setting: Choke, 38 mm.; main jet, No. 47 drill size; comp. jet, 1.70 mm. Barometer, 29.15 in. hg. February 15, 1921.

Data for all runs: Length of brake arm, 21 in.; kind of oil used, U. S. Spec. No. 3501, viscosity 115-125 at 210° F.; kind of fuel used, Aviation gasoline, W. D. Spec. No. 2-40; specific gravity of fuel, 0.707 at 60° F.

Carburetor test chamber—Variation of mixture ratio with altitude—Zenith carburetor, Model U. S. 52.

FULL THROTTLE.

Altitude in feet.	Standard setting.[1]		"Plain tube."[2]			Britton[3] setting, full rich.
			Setting (A).		Setting (B), full rich.	
	Full rich.	Full lean.	Full rich.	Full lean.		
Mixture ratio, lbs. air per lb. fuel.						
0	17.90	29.44	20.56	28.00	19.07	15.36
5,000	16.46	24.75	18.94	24.51	17.90	14.69
10,000	15.20	21.15	18.02	20.81	17.08	14.02
15,000	13.52	17.69	16.45	19.84	15.33	12.97
20,000	12.20	15.86	15.52	19.81	13.84	12.23
25,000	10.39	13.94	14.42	17.88	11.91	10.39
Fuel flow, lbs. per hour.						
0	81.8	50.7	70.6	51.8	75.4	93.7
5,000	74.6	50.6	64.7	50.0	67.1	81.8
10,000	67.9	49.2	56.4	48.9	62.1	75.5
15,000	62.6	48.3	50.9	42.0	57.3	67.7
20,000	54.9	43.2	43.2	34.0	51.9	59.5
25,000	51.1	38.6	37.2	30.1	50.3	58.2

[1] Standard setting: Choke, 36 mm.; main jet, 1.65 mm.: comp. jet, 1.70 mm.

[2] "Plain tube": Setting (A)—Choke, 36 mm.; main jet, 1.65 mm. comp. jet, 1.70 mm.; comp. fuel passage blank. Setting (B)—Choke, 38 mm.; main jet, 2.00 mm.; comp. jet, 1.70 mm.; comp. fuel passage blank.

[3] Britton setting: Choke, 36 mm.; Britton type discharge nozzle; main metering orifice No. 50 drill size; comp. jet, 1.70 mm.

Variation of mixture ratio with throttle opening (propeller load)—Zenith carburetor, Model U. S. 52, with Britton type discharge nozzle.

Nominal R. P. M. of engine.	Throttle opening, degrees.	Ground level.		20,000 feet	
		Full rich.	Blank comp. jet full rich.	Full rich.	Full lean.
Mixture ratio, lbs. air per lb. fuel.					
1,700	64 full	19.40	22.05	14.17	17.61
1,600	39	18.51	22.45	13.67	17.60
1,500	28	18.01	23.40	13.17	16.73
1,400	22	17.30	24.49	12.53	16.93
1,300	17	16.85	27.11	12.08	17.00
Fuel flow, lbs. per hour.					
1,700	64 full	75.8	66.1	48.5	39.9
1,600	39	69.2	57.6	45.3	35.8
1,500	28	62.1	48.0	40.9	32.1
1,400	22	55.0	38.9	35.7	26.9
1,300	17	46.6	28.8	28.2	19.8

Carburetor test chamber—Variation of mixture ratio with throttle opening (propeller load), Zenith carburetor, Model U. S. 52.

Nominal R. P. M. of engine.	Throttle opening, degrees.	Standard setting.[1]				Main jet only, ground level.		Comp. jet only,[2] ground level.	
		Ground level.		20,000 ft. altitude.					
		Full rich.	Full lean.	Full rich.	Full lean.	Full rich.	Full lean.	Full rich.	Full lean.
Mixture ratio, lbs. air per lb. fuel.									
1,700	64 full	17.94	29.44	12.35	14.61	23.68	27.80	72.83	1,034.0
1,600	39	17.77	27.88	11.85	14.25	25.05	28.80	65.00	211.0
1,500	28	17.28	26.23	11.50	13.74	25.85	30.40	57.10	116.0
1,400	22	16.80	23.20	10.84	13.39	27.30	32.60	48.70	77.6
1,300	17	16.05	21.20	10.48	12.72	29.27	35.55	40.40	53.2
Fuel flow, lbs. per hour.									
1,700	64 full	80.4	50.7	58.3	49.5	62.1	53.0	20.2	1.42
1,600	39	72.5	46.3	55.0	45.3	51.8	45.0	20.0	6.16
1,500	28	64.5	42.7	48.2	40.5	43.6	37.1	19.9	9.78
1,400	22	56.3	41.2	43.7	35.6	35.3	29.5	19.8	12.50
1,300	17	48.8	37.3	37.3	31.2	27.1	22.3	19.7	15.00

[1] Standard setting: Choke, 36 mm.; main jet, 1.65 mm.: compensating jet, 1.70 mm.

[2] Idle passages and compensating discharge nozzles functioning.

Zenith carburetor, Model U. S. 52, with compensating fuel passages blank ("plain tube").

Nominal R. P. M. of engine.	Throttle opening, degrees.	Ground level conditions.					20,000 feet, setting (B).	
		Setting (A).		Setting (B), full rich.	Blank[1] comp. jet, full rich.	Blank main jet, full rich.	Full rich.	Full lean.
		Full rich.	Full lean.					
Mixture ratio, lbs. air per lb. fuel.								
1,700	64 full	20.39	28.00	15.25	17.08	188.0	11.89	14.69
1,600	39	19.95	28.40	15.20	18.33	122.0	11.45	13.65
1,500	28	19.75	29.30	14.97	19.02	83.1	11.43	13.36
1,400	22	18.75	24.40	14.69	22.07	61.3	11.21	13.43
1,300	17	18.44	21.85	14.57	31.45	43.3	11.08	13.46
Fuel flow, lbs. per hour.								
1,700	64 full	71.2	52.1	96.0	85.2	7.86	59.3	48.3
1,600	39	64.3	45.7	83.8	70.2	10.53	55.1	46.2
1,500	28	56.2	38.2	74.2	58.5	13.43	47.5	41.3
1,400	22	50.4	39.1	64.2	42.4	15.46	40.8	33.9
1,300	17	42.4	36.1	53.4	24.7	17.98	34.4	27.4

[1] Main jet, 2.00 mm.

Setting (A): Choke, 36 mm.; main jet, 1.65 mm.; compensating jet, 1.70 mm. Setting (B): Choke, 38 mm.; main jet, 2.00 mm.; compensating jet, 1.70 mm.

Carburetor test chamber—Zenith carburetor, Model U. S. 52—Standard Liberty "12" setting, full throttle.

Variation of mixture ratio with air flow, ground level, full rich.		Variation of mixture ratio with float chamber vacuum.			
Air flow, lb. per sec.	Mixture ratio, lb. air/lb. fuel.	Altitude feet.	Float chamber vacuum in. H_2O.	Mixture ratio, lb. air/lb. fuel.	Position of control.
0.078	20.30	0	1.2	18.56	F. R.
.104	19.95	0	2.0	19.77	
.153	17.75	0	3.0	21.08	
.202	17.00	0	4.0	23.78	
.254	17.04	0	5.3	32.87	F. L.
.307	17.85	5000	0.8	17.77	F. R.
.359	18.30	5000	2.0	19.36	
.407	19.14	5000	3.0	21.98	
.458	19.25	5000	4.0	24.92	F. L.
.520	19.50	10000	0.6	17.11	F. R.
		10000	2.0	18.58	
		10000	3.3	22.50	F. L.
		15000	0.5	15.25	F. R.
		15000	1.5	17.01	
		15000	2.5	19.04	F. L.
		20000	0.3	13.18	F. R.
		20000	1.0	14.41	
		20000	1.8	16.60	F. L.
		25000	0.4	11.35	F. R.
		25000	1.0	12.87	
		25000	1.5	13.83	F. L.

Carburetor test chamber—Air flow through one carburetor, Liberty "12."—Full throttle.

Altitude, 1,000's feet.	Depression at carb. intake in Hg.	Density, per cent.	Wt. air, constant engine speed, lb. per sec.	Per cent of ground speed.	Wt. air, reduced speed,[1] lb. per sec.
0	0.2	100.00	0.405	100.0	0.405
5	4.1	86.29	.349	98.5	.344
10	7.8	73.70	.298	95.9	.286
15	11.2	62.37	.252	93.4	.235
20	14.2	52.37	.212	88.8	.188
25	16.8	43.68	.177	83.4	.148

[1] "Reduced speed" refers to the decrease in R. P. M. of the engine propeller unit at altitudes.

NOTE.—Measured weight of air at 1,700 R. P. M., full throttle ground level: Engineering Division test, 0.370 lb./sec.; Bureau of Standards test, 0.450 lb./sec.

Propeller load runs.

Nominal R. P. M.	Throttle opening, deg.	Air flow, per cent.	Air flow, lb./sec.
Ground level.			
1,700	64	100.0	0.405
1,600	39	88.6	.359
1,500	28	77.0	.312
1,400	22	65.5	.265
1,300	17	54.0	.219
20,000 feet altitude.			
1,700	64	100.0	0.188
1,600	39	88.6	.167
1,500	28	77.0	.145
1,400	22	65.5	.123
1,300	17	54.0	.103

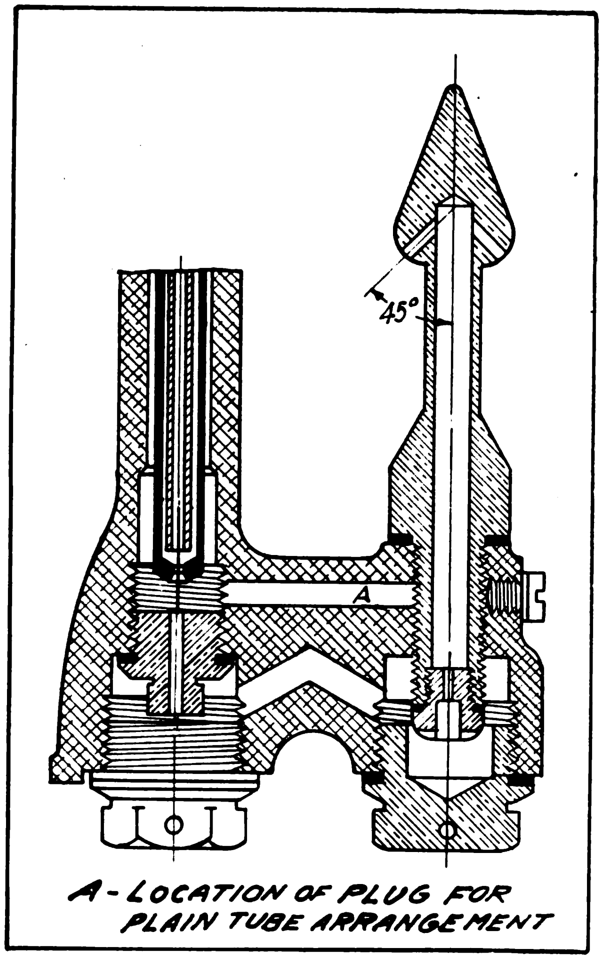


FIG. 15.—Britton type discharge nozzle and metering orifice as fitted to Zenith carburetor, Model U. S. 52.

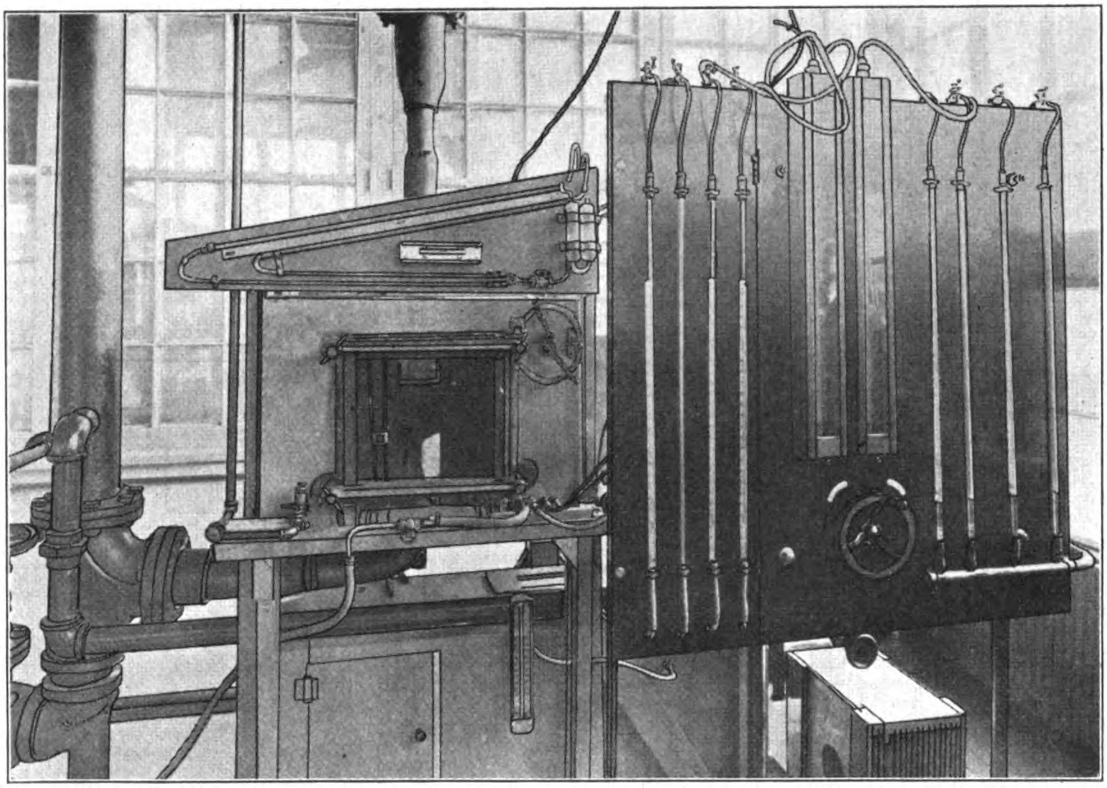


FIG. 16.—Carburetor test chamber and manometer board.

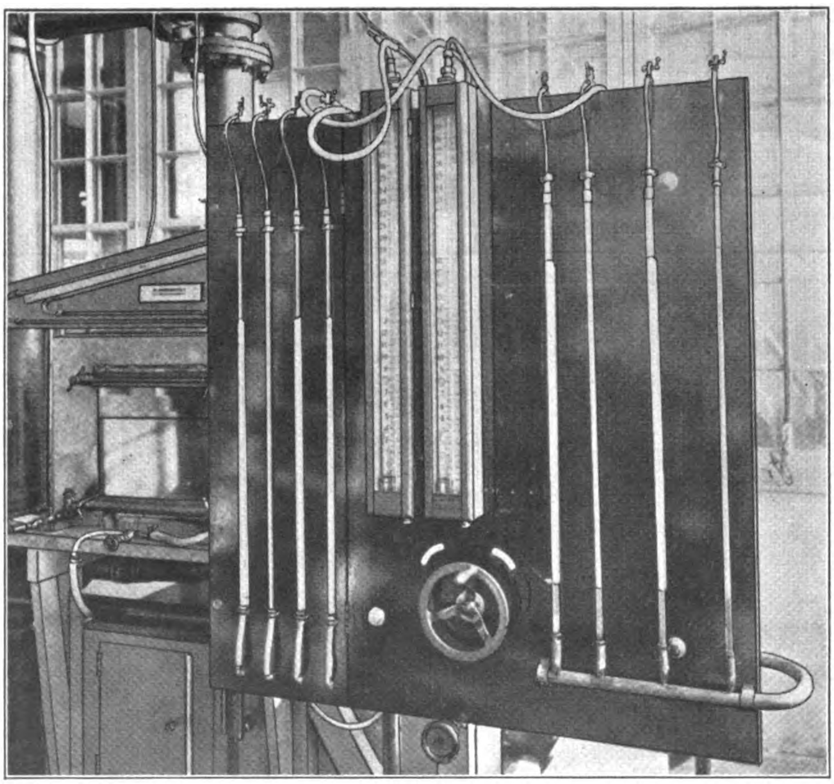


FIG. 17.—Carburetor test chamber and manometer board.

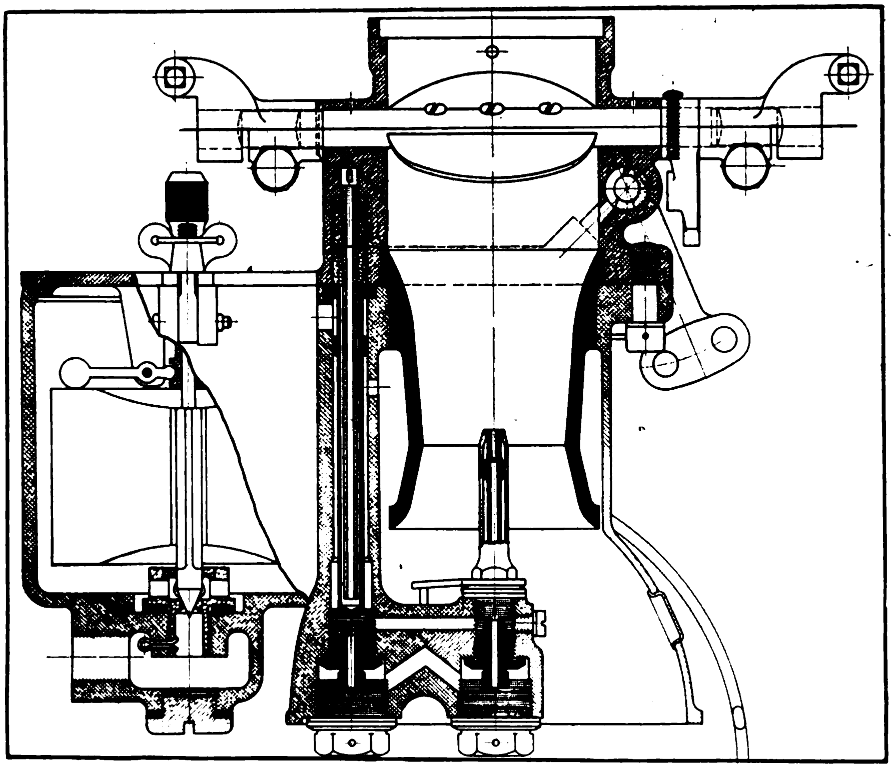


FIG. 18—Sectional view of Zenith carburetor, Model U. S. 52.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV October 15, 1922 No. 371

THE PHYSICAL PROPERTIES OF MANGANESE-BRONZE

(MATERIAL SECTION REPORT NO. 175)

▽

Prepared by
R. R. Moore
Engineering Division, Air Service
McCook Field, Dayton, Ohio
June 8, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

THE PHYSICAL PROPERTIES OF MANGANESE-BRONZE.

PURPOSE.

To determine the physical properties of manganese-bronze.

CONCLUSIONS.

The most important properties of manganese-bronze are as follows:

Proportional limit	11,000 lb. per sq. in.
Ultimate strength	69,000 lb. per sq. in.
Modulus of elasticity	14,200,000
Specific gravity	8.26

Shock resistance as measured by the notched bar test is good for a cast material.

MATERIAL.

As the maximum capacity of the available furnace in this laboratory is 350 pounds, it was necessary to divide the casting of test bars into three melts—No. 1616, 1618, and 1626—in order to obtain the desired number of specimens. Great care was taken to obtain these melts as near alike as possible, and the melt data given in Table 1 show that there is very little difference between the material of the three melts. Melts 1616 and 1618 were made from previously cast ingots plus sufficient extra zinc to raise the zinc of the resulting melts to the desired content. Melt 1626 was made from the gates and risers of equal weights of Melts 1616 and 1618. All melting was done in a Hausfeld No. 400 crucible tilting furnace, using gas fuel.

METHOD OF PROCEDURE.

Tension, compression, shear, torsion, impact, scleroscope, Rockwell, Brinell, and specific gravity tests were made. The method of casting test bars is shown in Figures 11 to 15. The type of specimens cut from these bars is shown in Figures 1 to 10. In the case of the tension modulus specimens shown in Figure 4 a Ewing extensometer was used for measuring elongation over an 8-inch gage length. With the torsion specimen shown in Figure 5 a special deflection meter was used which measured deflections to 0.01 inch on a 12-inch radius. By the use of these measuring instruments a very accurate determination of proportional limits was possible, it being selected as the highest point on the straight line section of the curve. Contraction in length of the compression specimen was measured with a Berry Extensometer.

RESULTS.

The first tests run on each of these melts were the tension tests of the 2-inch gage length specimens. It so happened that in each of these melts one of the two tension specimens contained quite noticeable slag inclusions which reduced the elongation about 50 per cent and the breaking strength about 9½ per cent. The values given in Table 2, first column, are the averages of the three clean specimens of these melts. The values in the second column of this table are those of Melt 1626, as the specimens from Melt 1616 showed segregation and Melt 1618 is being held for a future test. The compression value is the average of six specimens from Melt 1626; they all checked very closely. The torsion value is the average of two specimens of Melt 1626. The shear value is the average of five specimens from Melt 1626. The Charpy impact with V notch and Izod impact with round and V notch are each the average values of eight tests of specimens from Melt 1626. The Charpy impact, round notch, is the average of four specimens from Melt 1616 and four from 1618; both of these melts checked very closely.

DISCUSSION OF RESULTS.

It should be noticed from Table 2 that the elongation of the 8-inch tension specimen is very uniform over the entire gage length, not varying more than 2 per cent between 2 and 8 inches. In accordance with this, the reduction of area is also very uniform over the whole length of the bar, the largest difference in the diameter being about 0.003 inch. Incidentally, this reduction of area is quite small, being only 20½ per cent.

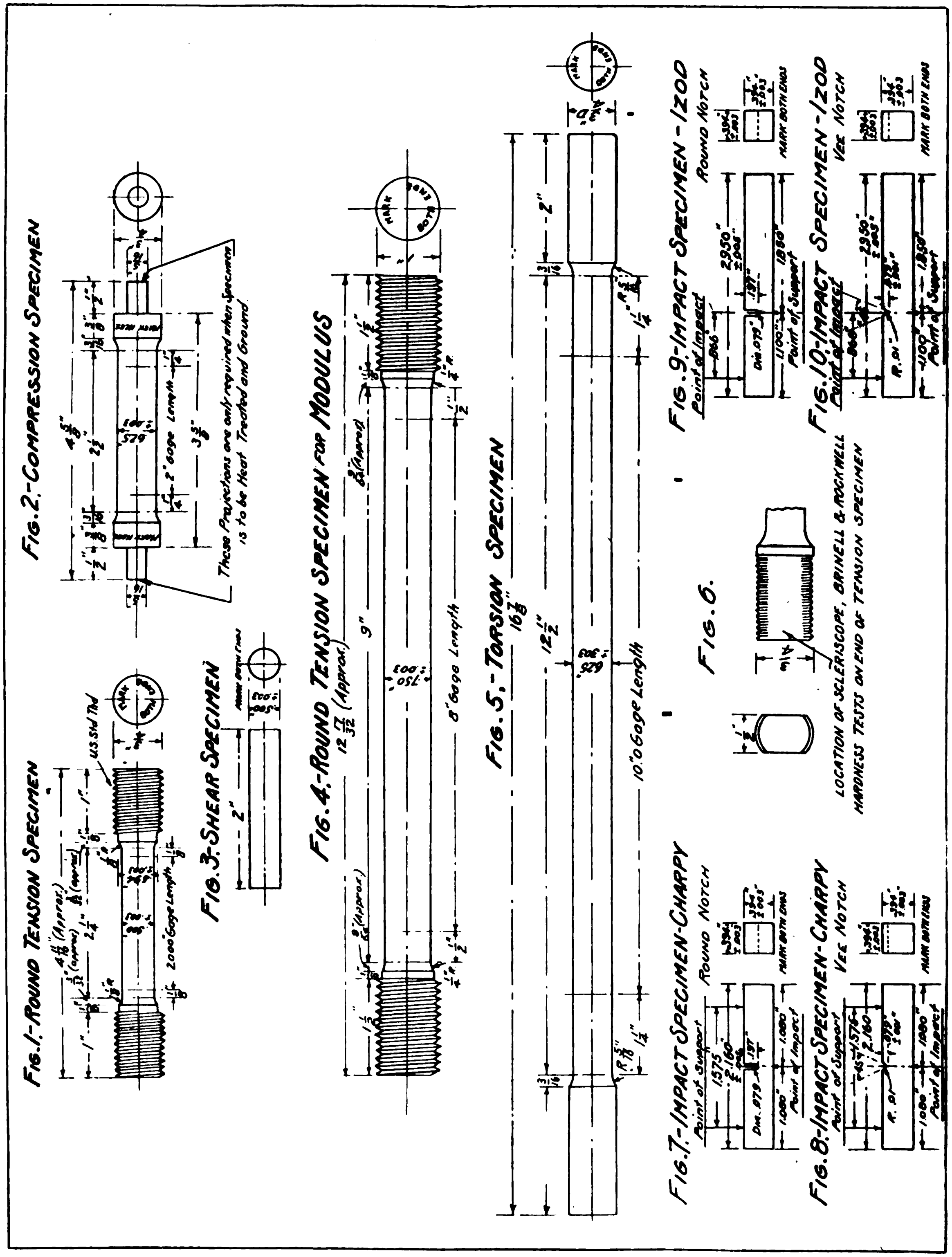
Stress-strain curves for tension and torsion are shown in figure 16.

The compressive strength seems to be very small, which was rather unexpected. The type of specimen used here has been used on all investigations in this laboratory, and for steels usually gives a compressive strength nearly equivalent to the tensile strength. This result is the average of six tests, all of which checked closely so that the value is quite reliable.

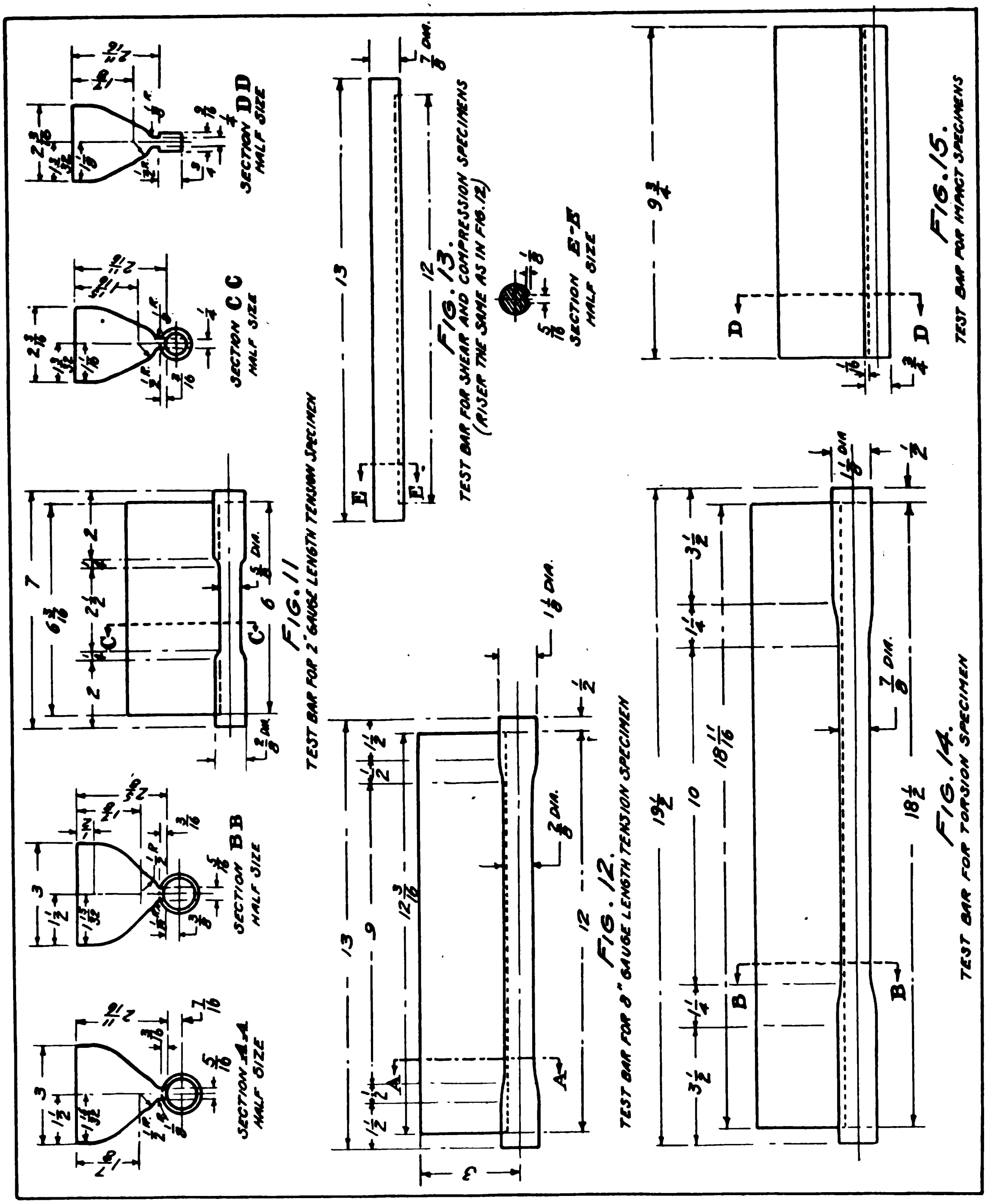
The shearing strength is about 0.62 of the tensile strength which corresponds to the same relation for steels.

The V impact notch values are higher than the round notch values, and the Charpy values higher than the Izod values. The same has been found to be true for some alloy steels. The values themselves are about as good as can be expected for cast material.

In addition to the above tests, 30 fatigue specimens were cast and will be tested on the rotating beam type of machine in the near future.



FIGS. 1 to 10.—Standard test specimens.



Figs. 11 to 15.—Method of casting test bars.

METALLOGRAPHY.

Two microphotographs, one at 100 and one at 500 diameters, were taken on a transverse section of the end of the 8-inch tension specimen from Melt 1626 and are shown in Figures 17 and 18. The specimen was polished in the usual manner and etched with NH_4OH and H_2O_2.

The structure of the material tested consists of a matrix of beta prime in which are imbedded particles of alpha (mottled) and minute particles of delta prime (white). The quantity and size of the alpha is satisfactory and the distribution of the delta prime is normal except that a tendency toward segragation was noted in several areas of the specimen examined.

TABLE 1.—*Melt data.*

Melt No.	1616	1618	1626
Chemical composition:			
Sn	0.32	0.32	0.42
Cu	56.85	56.67	56.72
Fe	1.45	1.55	1.55
Al	.25	.22	.22
Mn	.20	.20	.20
Zn	Difference.	Difference.	Difference.
Max. furnace temp. (Deg. Fahr.)	1760	1760	1780
Pouring temperature (Deg. Fahr.)	1750	1760	1780
Time in furnace	2 hr. 10 min.	2 hr. 15 min.	1 hr. 50 min.
Number test bars from each melt.	2, Fig. 11; 1, Fig. 12; 1, Fig. 15; 15, fatigue.	2, Fig. 11; 1, Fig. 12; 1, Fig. 15; 15, fatigue.	6, Fig. 15: 3, Fig. 13; 3, Fig. 14; 1, Fig. 12: 2, Fig. 11.

TABLE 2.—*Average results of tests.*

Kind of test.	Tension.		Compression.	Torsion.	Shear.	Impact.	
	2″ spec.	8″ spec.				Izod.	Charpy.
Proportional limit, lb. per sq. in.	*32,340	10,940	15,500	11,140			
Ultimate strength, lb. per sq. in.	72,960	69,500	42,390		43,190		
Elongation:							
Per cent in 2 in.	32.8	30					
Per cent in 4 in.		29					
Per cent in 8 in.		28					
Reduction of area		20.6					
Modulus of elasticity		14,235,250		4,619,000			
Modulus of rupture				61,890			
Energy absorbed, ft-lb.:							
R						18.4	21.03
V						29.4	34.41
Scleroscope No.	17						
Brinell No. 500 kg.	93						
Rockwell No. 100 kg., 1/16-in. ball	65						
Specific gravity	8.26						

* This value is yield point instead of proportional limit. It was obtained by the divider method, as being the point at which first signs of visible stretch appeared.

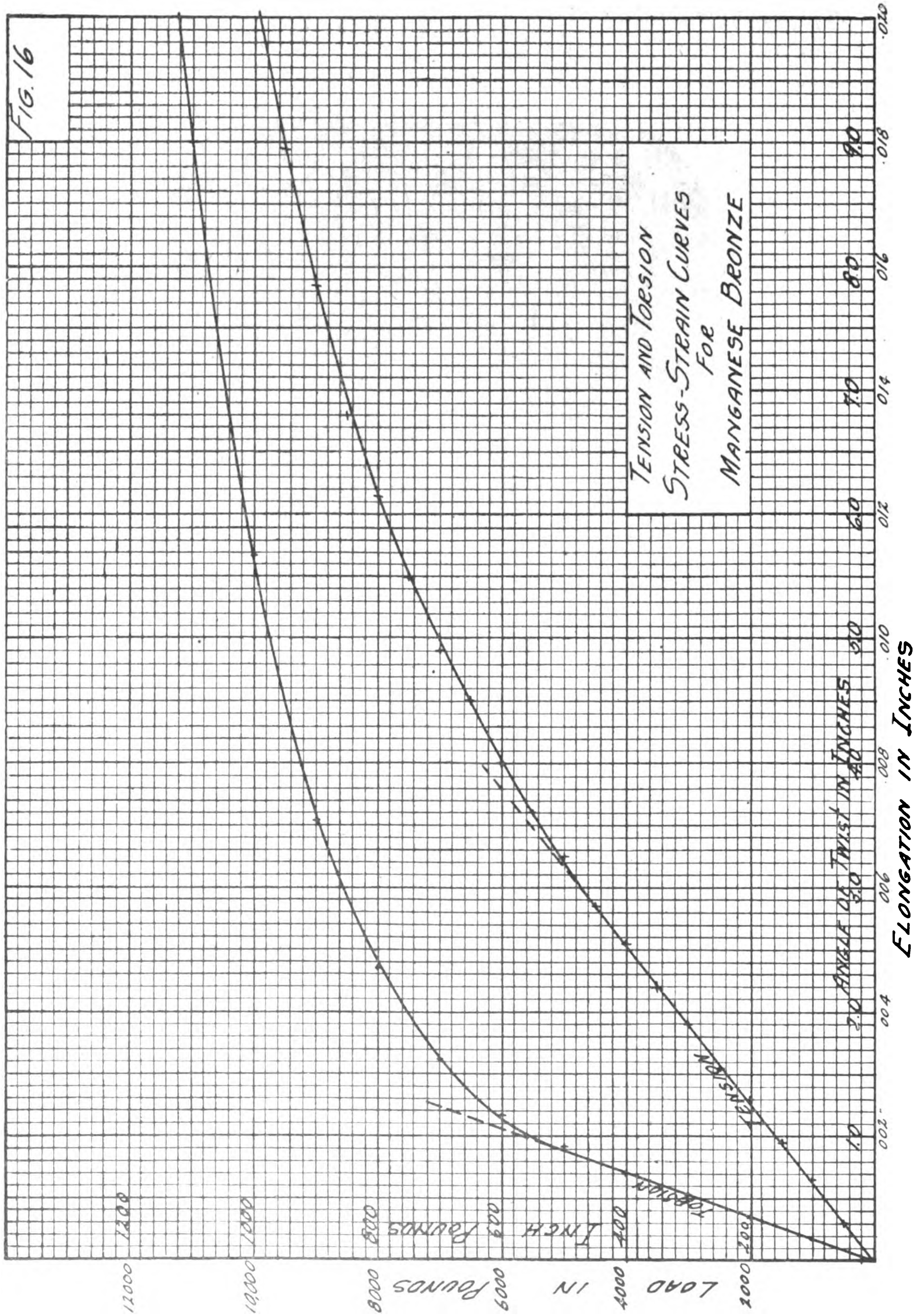


FIG. 16
TENSION AND TORSION
STRESS-STRAIN CURVES
FOR
MANGANESE BRONZE
ELONGATION IN INCHES
ANGLE OF TWIST IN INCHES
LOAD IN POUNDS
INCH POUNDS
TENSION
TORSION
.002 .004 .006 .008 .010 .012 .014 .016 .018 .020
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0
2000 4000 6000 8000 10,000 12,000
200 400 600 800 1000 1200

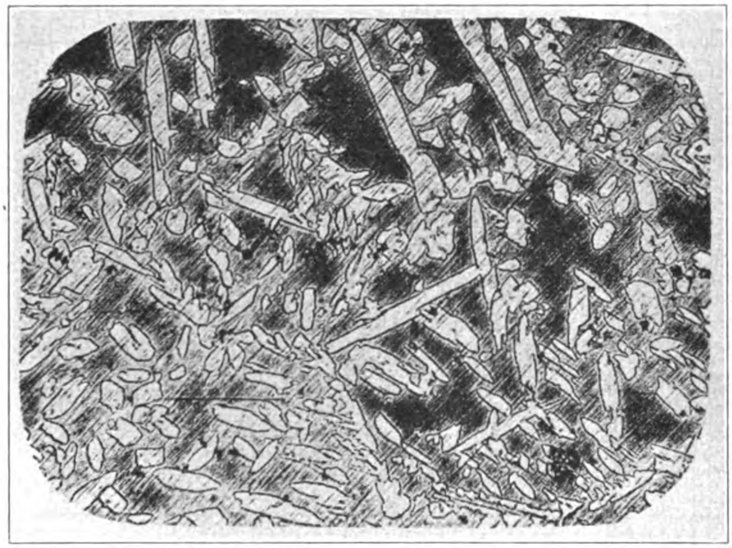


FIG. 17.—Magnification 100 diameters.

FIG. 18.—Magnification 500 diameters. Etching: $HN_4OH+H_2O_2$. Remarks: Alpha mottled and delta prime clear white. Normal structure representing good combination of strength and elongation.

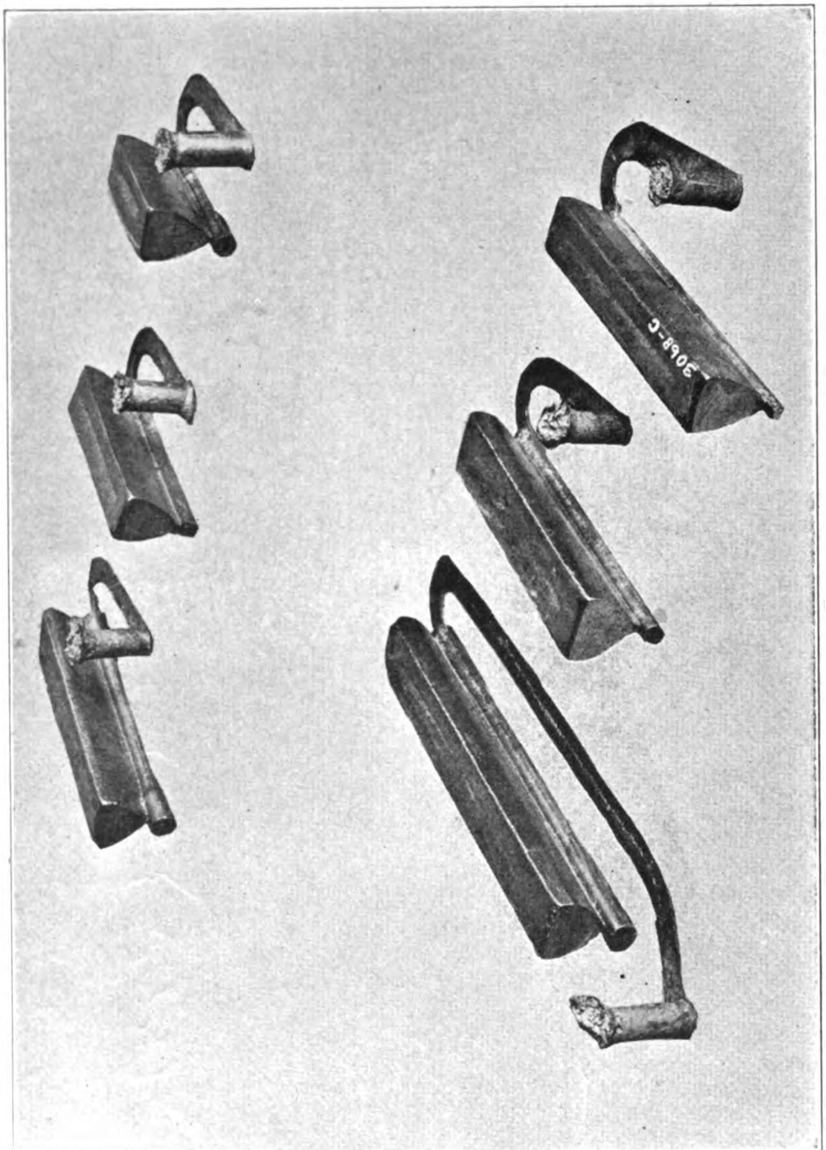


Fig. 19.—Methods of gating.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV September 1, 1922 No. 372

FLIGHT TEST OF ANTI-KNOCK INJECTOR

(POWER PLANT SECTION REPORT)

△

Prepared by O. C. Christiansen, A. M. E.
Engineering Division, Air Service
McCook Field, Dayton, Ohio
May 19, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

FLIGHT TEST OF ANTI-KNOCK INJECTOR.

OBJECT OF TEST.

The object of this test was to determine if the injection of an antidetonating compound into the manifold of an engine is practicable.

SUMMARY.

When the injector was in working order and set to feed the proper amount of compound, detonation appeared to be eliminated except during acceleration. Due to mechanical troubles in the injector and imperfections in its action, in the form in which it was tested, the research work was discontinued.

CONCLUSIONS.

The effective injection of antidetonating compound is possible, but further experimentation is not recommended until it has been definitely shown that this method of introducing the compound is necessary. At the present time it appears that mixing the compound with the fuel in the tanks is to be preferred, due to the absence of mechanical complication.

INTRODUCTION.

Some experiments have been carried on by the Engineering Division with antidetonating compounds, but they have not proved entirely satisfactory because the compounds have been more or less poisonous and consequently dangerous to handle, because the compounds caused serious corrosion of the fuel tanks and piping, and finally because they are very expensive.

It was hoped that the injection of antiknock at the intake manifolds, at relatively high power operation at low altitudes only, would avoid the waste of compound and prevent the injury to fuel tanks and lines now encountered when mixing the antiknock with the gasoline. An injecting device to accomplish these results was therefore constructed.

DESCRIPTION.

The device tested was manufactured by the General Motors Research Corporation, of Moraine City, Ohio. It is constructed of a cast-iron body which incorporates a brass float chamber somewhat similar to that of a carburetor. The delivery passage from the float chamber is controlled by a sleeve valve operated by an aneroid (see fig. 5). The principle of the device is to admit antidetonating compound directly into the manifold as near the cylinders as possible during full throttle operation and an extra large quantity at the moment of acceleration. The compound or solution, which in this case was xylidine, flows through the inlet shown on the drawing, and the level in the chamber is regulated by a cork float (balsa wood was later substituted by the engineering division). Two holes drilled at A meter the maximum amount of xylidine fed by the injector. The valve B, as the drawing indicates, is actuated by the aneroid, which in turn reacts to the manifold depression. As the throttle is opened the depression decreases until the valve B opens. This depression, when the valve is open, causes the xylidine to flow into the manifold and mix with the incoming charge. If the throttle is closed the depression increases and closes the valve B. A well C is provided for the purpose of delivering a relatively large quantity of the compound during acceleration. This was later supplemented by an additional well D.

The adjustment of the instrument is such that the valve B starts to open when the absolute pressure in the aneroid chamber reaches 20 inches of mercury. As the pressure increases above this point the valve opening increases, until at an absolute pressure of about 28 inches of mercury the valve B is wide open and the fuel is metered by orifice A.

The pressure in the engine manifold is governed both by the throttle opening and the atmospheric pressure. Above an altitude of about 10,000 feet the pressure in the manifold is always less than 20 inches Hg, and consequently no compound would be delivered. Twenty-eight inches Hg pressure in the manifold corresponds to full throttle opening at sea level.

METHOD OF TEST.

A Liberty "12" engine, standard except for pistons, which had a compression ratio of 6½:1, was installed in a DH-4B airplane. The entire test was conducted in the airplane on the ground and in flight, with aviation gasoline War Department Specification No. 2-40.

The test was conducted with the following groups of equipment:

1. Four dope injectors were installed, each independent and feeding one manifold, drawing the xylidine from a small tank placed at and above No. 5 left cylinder.
2. One dope injector feeding all the manifolds and supplied by the same tank mentioned above but located on the center section of the airplane.
3. One dope injector and tank as before with the addition of four distributor valves, illustrated in Figure 1, which metered the amount of compound to be supplied each manifold.
4. The same arrangement as mentioned under item No. 3 except for the substitution of a 5-gallon tank.

Ground tests consisted of accelerating rapidly and running the engine full out, meanwhile listening for any detonation. When the distributor valves shown in Figure 1 were installed the flow was observed through the

sight gauges. The aërial tests consisted of level flights which were made around 2,000 feet and of 30 or 40 minutes' duration. Here again observations of detonation were made. This routine was carried out with each change of equipment. After landing, the spark plugs were inspected. The flights to determine the consumption were made as follows:

(*a*) Climb at full throttle to 3,000 feet altitude and fly level at full throttle. The total duration of a flight, including the climb, should be one hour.

(*b*) Make a similar flight at 1,500 revolutions per minute. Climb should be made at full throttle.

RESULTS OF TEST.

The difficulties may be summarized under two heads, viz., operative troubles not attributable to the injector and mechanical troubles in the injector itself.

When the flights were made with four injectors, it was found that the porcelain spark plugs failed by cracking of the insulator and burned electrodes, such as is usually the case with high-compression engines when detonation is severe. The failures appeared to be largely confined to the right front manifold. The right rear manifold appeared to be receiving an excess of xylidine, indicating that the distribution was not equalized. For this reason, one injector was advocated. It was also believed that more consistent operation would be obtained by moving the xylidine tank from its position on the engine to the center section of the airplane, to increase the fuel head. A single injector was finally installed between No. 1 right and left cylinders. Further flights with this arrangement showed that detonation was still present and that the distribution to the various manifolds was not uniform. Detonation was also observed when accelerating the engine from idling speed. To observe the distribution and operation of the injector during acceleration, four distributor valves were installed between the injector and the manifolds. At the same time the feed lines from the injector to the manifolds were shortened about 12 or 14 inches to an irreducible minimum with the existing equipment. This change was made to prevent any lag of the xylidine during acceleration. A one-hour flight was attempted to measure the amount of xylidine used, but the 1-gallon tank proved of insufficient capacity and a 5-gallon tank was therefore substituted. The flights were then made, the results of which are noted later in this report.

Several mechanical difficulties occurred. The cork floats used in the single injector expanded and became jammed in the float chamber or lost their buoyancy by absorbing the compound used to eliminate detonation. The float needle valve became gummed up and jammed several times. The instrument therefore flooded and leaked over the top of the float bowl and a considerable amount of xylidine flowed into the aneroid chamber. To overcome the troubles with the float, experiments were conducted with balsa wood. A piece of cork and one of balsa wood, both untreated, were placed in a container of xylidine for 20 days. The dimensions of the 2 pieces before and after this period of immersion were as follows:

	Cork.	Balsa wood.
Before immersion.........	[illegible] inch × 1 inch × 1[illegible] inches.	1 inch × 1 inch × 1 inch.
After immersion..........	[illegible] inch × 1[illegible] inches × 1[illegible] inches.	1[illegible] inches × 1[illegible] inches × 1 inch.

The expansion of the balsa wood was scarcely appreciable, while the cork expansion was extreme. The cork had also lost its buoyancy so that the top surface was almost immersed. The balsa wood, on the other hand, was apparently as buoyant as before tested. The test pieces were broken and the cork was found saturated throughout, while the balsa wood contained a considerable area at the center which was perfectly dry. The comparative value of these two articles for float material is shown by the much more satisfactory performance of the balsa wood in the present injector when one was installed on the injector during this test.

In tightening the nut on the bottom of the float chamber bowl to prevent leakage, the drilled cast-iron boss was broken off on several of the injectors tested.

The following consumption of xylidine and fuel was observed in flight:

Duratin of flight, 1 hour; altitude, 3,000 feet; full throttle, 1,740 revolutions per minute:

- Fuel consumed......................gallons.. 34
- Xylidine consumed..................quarts.. 5
- Per cent, by volume, of xylidine to total fuel used...................................... 3.5

Duration of flight, 62 minutes; altitude, 3,000 feet; throttled to 1,500 revolutions per minute:

- Fuel consumed......................gallons.. 25
- Xylidine consumed..................quarts.. 3
- Per cent, by volume, of xylidine to total fuel used...................................... 2.9

ANALYSIS.

The tests have shown that this method of injection is sound and can be worked out in a satisfactory manner, possibly with better economy of the compound than by any other method. It has further been shown that the present means for accomplishing the injection of antiknock compounds is unsatisfactory from a mechanical standpoint. It is suggested that an injector should be so constructed as to preclude the possibility of leakage on any part of the engine or airplane from high-grade materials able to withstand the usage to which it is subjected in service. The float mechanism should be positive in action and reliable. Any possibility of the antidetonating solution reaching the aneroid should be prevented. The amount of the xylidine found necessary in laboratory tests was 5 per cent by volume, so that the unit used effected a saving of 30 per cent of the compound at full throttle, 3,000 feet altitude.

Cheaper compounds are now being developed, and it is probable that the mixing of these with the fuel will be practicable. On account of the mechanical complication of the injection method, it is recommended that no further research work be conducted at the present time.

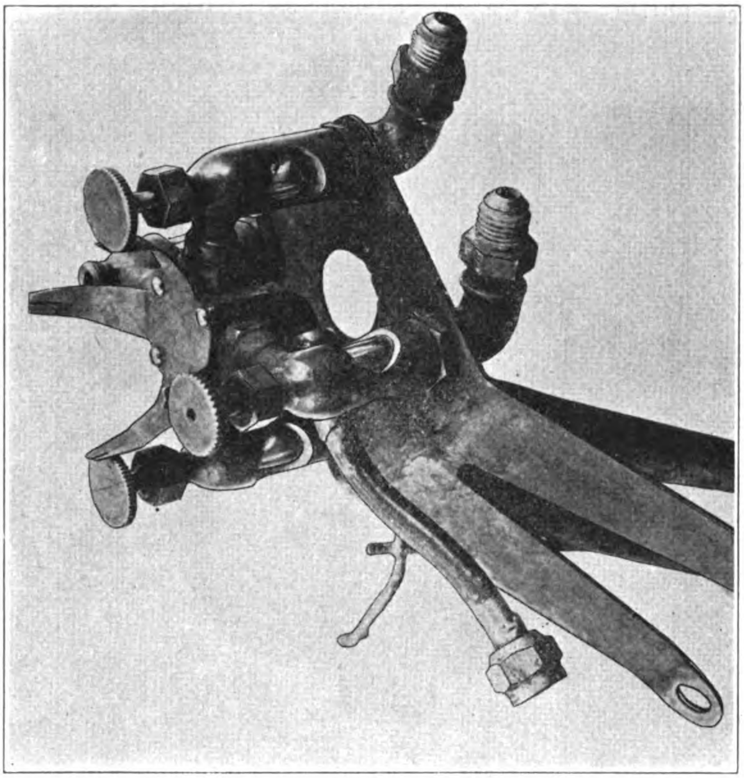


Fig. 1.—Distributor valves with sight gages.

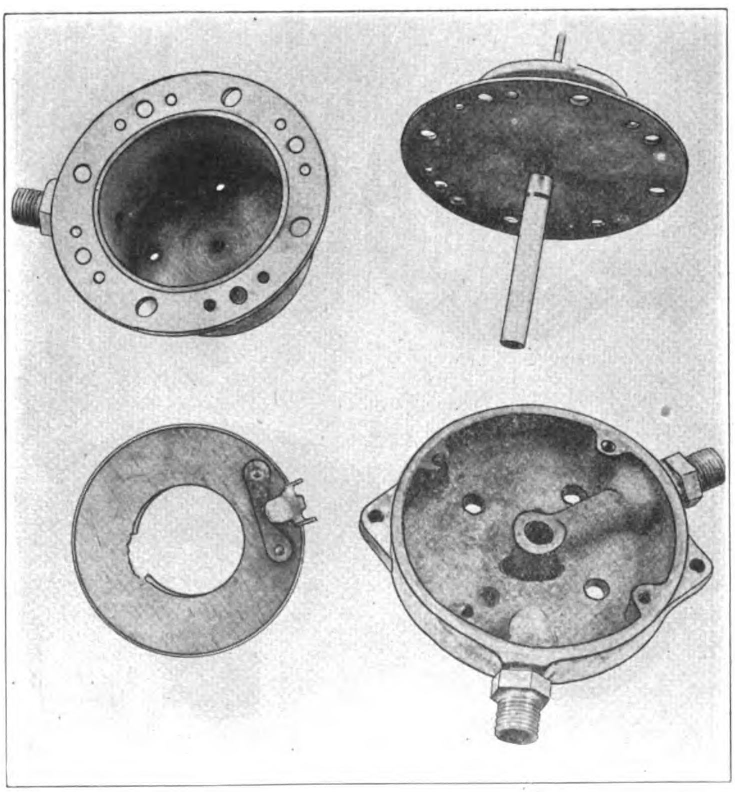


Fig. 2.—Anti-knock injector details.

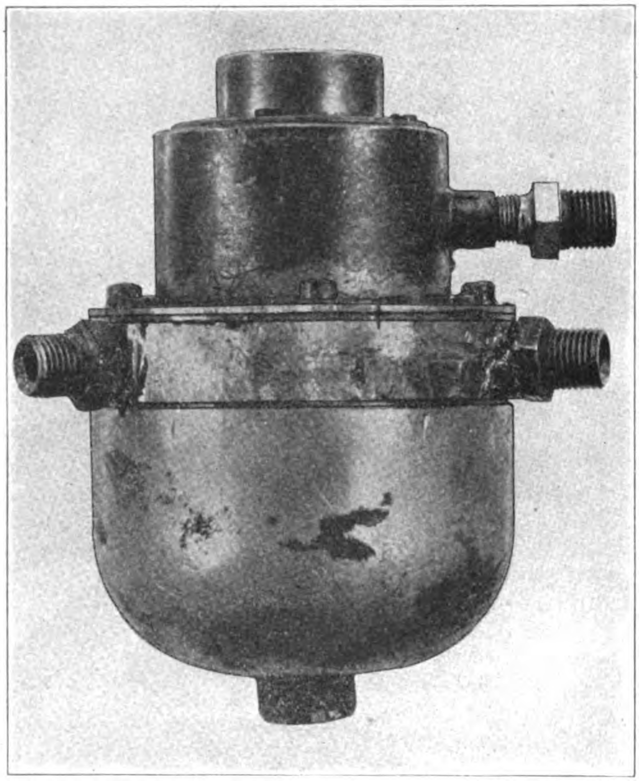


FIG. 3.—Anti-knock injector assembly.

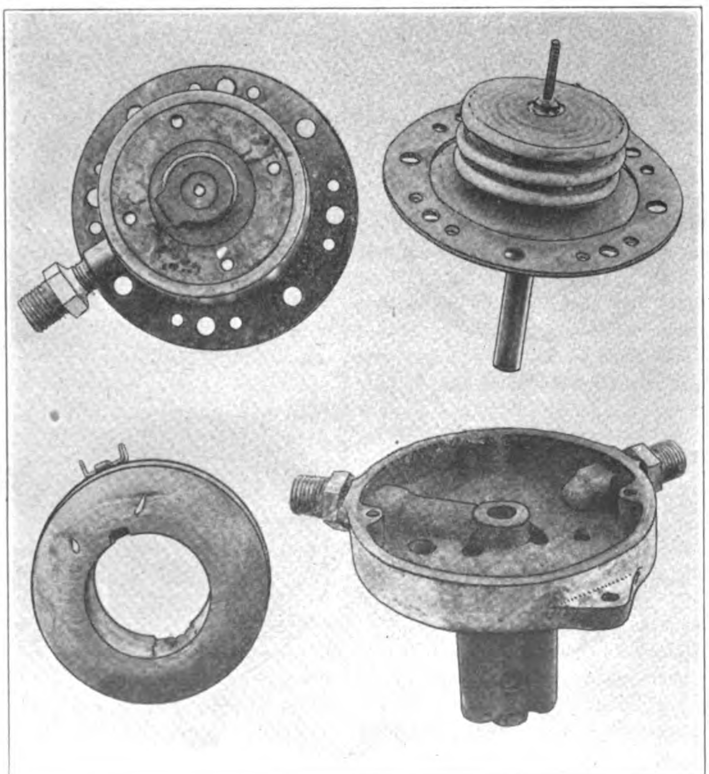


FIG. 4.—Anti-knock injector details.

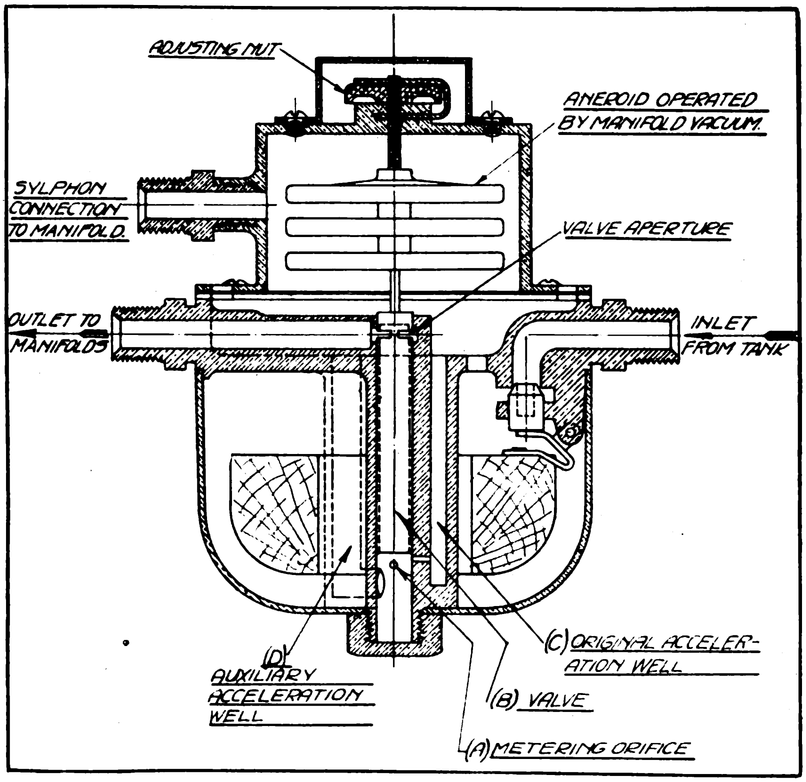


FIG. 5.—Diagrammatic cross sectional view of anti-knock injector.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV October 15, 1922 No. 373

TEST OF CURTISS EIGHT-CYLINDER MODEL OX-5 ENGINE RATED AT 90 HORSEPOWER AT 1,400 REVOLUTIONS PER MINUTE

(POWER PLANT SECTION REPORT)

▽

Prepared by O. C. Christiansen
Engineering Division, Air Service
McCook Field, Dayton, Ohio
May 16, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

TEST OF CURTISS EIGHT-CYLINDER MODEL OX-5 ENGINE RATED AT 90 HORSEPOWER AT 1,400 REVOLUTIONS PER MINUTE.

OBJECT OF TEST.

The object of the test was to obtain reliable data for use by airplane designers on the performance of the Curtiss OX-5 engine.

SUMMARY OF RESULTS.

Normal brake horsepower at full throttle, 98.5 B. H. P. at 1,400 R. P. M.

Fuel consumption at normal horsepower, 0.490 pounds per B. H. P. hour.

Oil consumption at normal horsepower, 0.0228 pounds per B. H. P. hour.

Normal brake mean effective pressure, 111.0 pounds per square inch.

Total weight, dry, 377.0 pounds.

Weight dry per B. H. P., 3.83 pounds.

CONCLUSIONS.

In view of the eminent reliability of this type of engine during the World War no comment on this engine is necessary. From a technical standpoint the general performance and fuel and oil consumption of the engine are very good and it is well adapted for use in training airplanes. The engine developed no trouble of any kind during the test and revealed no point of excessive vibration. The carburetion appeared to be good at all speeds. Plugging one oil breather did not cause the loss of any oil or affect the engine operation in any way.

DESCRIPTION OF ENGINE.

The engine tested is a Curtiss Model OX-5 Air Service Serial No. 10536, eight-cylinder, Vee type, designed with a staggered cylinder arrangement more clearly understood by reference to figure 3. It is of the four stroke cycle, water cooled, tractor type and uses aviation gasoline as fuel. The propeller is directly driven from the crankshaft. The engine is one of several types designed by the Curtiss Aeroplane & Motor Corporation of Garden City, Long Island, N. Y. This particular engine was manufactured by the Willys-Morrow Co. (Inc.), of Elmira, N. Y. For additional illustrations see figures 1 and 2.

The characteristic features on this engine are the staggered cylinders, side-by-side connecting rods, the unique push rod arrangement and the location of the carburetor at the rear of the engine.

A great many handbooks and much information is available on this engine but perhaps the best is "The Curtiss Standard Model OX Aeronautical Motor Handbook" issued by the manufacturers. For more detailed information on various points not covered in this report the reader is referred to the handbook just mentioned.

METHOD OF TEST.

The test of this engine followed more or less closely the "Instructions for Conducting Standard Engine Tests." No part photographs, weights, or dimensions were taken. The following runs were made:

Two full-power runs.

A friction horsepower and compression pressure run.

A carburetion run.

A one-hour fuel and oil consumption run.

A water pump capacity run when pumping through the engine.

The fuel used for the test was domestic aviation gasoline and was measured by volume. The oil used was within the limits set by specification 2-23B. The power was measured by a Sprague electric dynamometer, the electrical resistance of which was adjusted to absorb the power output of the engine. For further details on the method of testing see Engineering Division reports, Serial Nos. 1506 and 1507.

The "carburetor vacuum" (see figure 5) was taken at the throat of the right-hand venturi tube.

ENGINE DATA.

Bore	4 inches.
Stroke	5 inches.
Compression volume	16.05 cubic inches.
Total cylinder displacement	502.80 cubic inches.
Compression ratio	4.92 to 1.
Rotation of propeller (facing propeller)	Counterclockwise.
Firing order	1-2-3-4-7-8-5-6.
Method of numbering cylinders	See figure 3.

Timing, actual average:

	Opens.	Closes.
Inlet	17° ATC	41° ABC
Exhaust	49° BBC	3° ATC

Power plant weight:[1]

	Pounds.
Engine weight, dry	377.0
Power plant constant weight	28.10
Cooling system	64.03
Tankage	59.75
Fuel, 2½ hours sea level full throttle	118.00
Oil, 2½ hours sea level plus 22 pounds reserve	27.50
Total	674.38
Weight per horsepower (power plant)	6.85
Weight per horsepower (engine, dry)	3.83

Carbureter setting:

	Mm.
Chokes	22
Main jets	1.20
Compensators	1.00

[1] See power plant weight table in Engineering Division report serial No. 1506.

FULL-POWER RUNS.

FIRST RUN.

R.P.M.	Actual— Brake load, lb.	Actual— B.H.P.	Corrected— Torque lb.-ft.	Corrected— Hp.	B.m.e.p. lb. per sq. in.	Water— Temp. °F. In.	Water— Temp. °F. Out.	Oil press. lb. per sq. in.	Carb. air temp. °F.	Man. vac. in. Hg.	Carb. vac. in. Hg.	Mix.[1] cont. position.	Fuel cons. Lb. per hr.	Fuel cons. Lb. per hp. per hr.
850	199	56.4	363.0	58.8	108.9	150	170	58	50	0.4	1.2	Full Rich	36.2	0.642
950	211	66.8	385.0	69.6	115.5	145	165	60	50	0.5	1.5	1.80	....	....
1,050	216	75.6	394.0	78.8	118.1	142	167	60	50	0.6	1.6	1.25	39.2	.518
1,160	216	83.6	394.0	87.2	118.1	150	164	63	50	0.7	1.8	1.65	....	....
1,230	214	87.8	390.5	91.5	117.1	155	170	62	50	0.8	2.0	1.5	43.6	.497
1,340	209	93.4	381.5	97.4	114.4	152	168	62	50	0.9	2.0	1.5	....	....
1,400	206	96.2	376.0	100.3	112.8	160	145	62	50	1.0	2.1	1.5	46.7	.485
1,490	200	99.4	365.0	103.6	109.5	170	158	60	50	1.1	2.3	1.5	....	....
1,620	192	103.7	350.5	108.1	105.1	166	156	60	52	1.3	2.5	1.7	51.2	.494

Average barometer, 28.70 in. Hg.

SECOND RUN.

R.P.M.	Actual— Brake load, lb.	Actual— B.H.P.	Corrected— Torque lb.-ft.	Corrected— Hp.	B.m.e.p. lb. per sq. in.	Water— Temp. °F. In.	Water— Temp. °F. Out.	Oil press. lb. per sq. in.	Carb. air temp. °F.	Man. vac. in. Hg.	Carb. vac. in. Hg.	Mix.[1] cont. position.	Fuel cons. Lb. per hr.	Fuel cons. Lb. per hp. per hr.
830	210	58.1	384.0	60.8	115.2	155	170	57	60	0.4	1.1	1.5	37.5	0.646
940	217	68.0	397.0	71.1	119.1	156	170	55	58	0.6	1.4	1.5	....	....
1,040	220	76.3	402.5	79.8	120.8	156	168	58	56	0.7	1.5	1.5	41.3	0.541
1,110	215	79.6	393.4	83.2	118.0	160	178	60	56	0.7	1.6	1.5	....	....
1,200	216	86.4	395.2	90.3	118.6	156	170	61	56	0.8	1.8	1.5	43.3	0.501
1,330	210	93.1	384.0	97.4	115.2	148	160	60	56	1.0	2.0	1.6	....	....
1,420	206	97.5	376.9	101.9	113.0	156	168	60	56	1.1	2.1	1.5	46.9	0.481
1,540	200	102.7	366.0	107.4	109.8	160	149	60	64	1.1	2.4	1.5	....	....
1,590	195	103.4	356.8	108.1	107.1	174	154	60	61	1.2	2.5	1.5	52.3	0.506

Average barometer, 28.62 in. Hg.

[1] The control was full lean at 1.2 and full rich at 3.2.

PROPELLER LOAD RUNS.

FIRST RUN.

R. P. M.	Actual— Brake load lb.	Actual— B. H. P.	Corrected horsepower.	Water temp. °F. In.	Water temp. °F. Out.	Oil press. lb. per sq. in.	Carb. air temp. °F.	Man. vac. in. Hg.	Carb. vac. in. Hg.	Mix.[1] cont. position.	Throttle position.	Fuel cons. Lb. per hr.	Fuel cons. Lb. per hp. per hr.
1,430	205	97.8	100.4	156	170	62	58	1.1	2.2	1.5	10	47.9	0.490
1,190	148	58.7	60.3	162	174	61	60	6.4	0.8	1.5	1.5	29.9	.509
1,010	105	35.4	36.4	162	174	59	62	9.9	0.4	1.5	1.0	21.4	.604
820	67	18.3	18.8	160	168	57	64	14.6	0.1	1.5	0.9	15.2	.830

SECOND RUN.

R. P. M.	Actual— Brake load lb.	Actual— B. H. P.	Corrected horsepower.	Water temp. °F. In.	Water temp. °F. Out.	Oil press. lb. per sq. in.	Carb. air temp. °F.	Man. vac. in. Hg.	Carb. vac. in. Hg.	Mix.[1] cont. position.	Throttle position.	Fuel cons. Lb. per hr.	Fuel cons. Lb. per hp. per hr.
1,410	201	94.5[2]	97.0	156	170	60	64	1.2	2.6	3.2	10	52.6	0.556
1,410	202	95.0	97.5	154	168	60	64	1.0	2.0	1.2	....	46.0	.485
1,210	150	60.5[2]	62.1	158	170	60	64	6.5	1.0	3.2	1.4	33.1	.547
1,190	142	56.3	57.8	156	168	60	64	6.6	0.7	1.2	....	29.3	.521
1,000	104	34.7[2]	35.6	154	166	64	68	10.6	0.4	3.2	0.9	23.0	.662
1,030	96	33.0	33.9	155	168	65	70	10.9	0.3	1.75	....	20.1	.610
810	68	18.4[2]	18.9	150	161	60	72	17.0	0.1	3.2	0.7	15.5	.844
820	66	18.0	18.5	160	172	60	72	16.5	0.1	0	....	12.8	.713

Average barometer; 29.14 in. Hg.

[1] The control was full rich at 3.2 and full lean at 1.2.
[2] The readings marked with (2) were with full rich mixture; the others were with best setting of the control at each speed.

FRICTION HORSEPOWER RUN.

R. P. M.	Corrected engine B. H. P. (from curve).	Friction load (lb.).	F. H. P.	F. M. E. P. (lb. per sq. in.).	Per cent mech. eff.	Comp. press. (lb. per sq. in.).	Water temp. °F. In.	Water temp. °F. Out.	Air temp.
120	....	....	....	....	....	78	....	....	....
800	54.5	21	5.9	11.6	90.2	....	156	168	50
900	64.1	21	6.6	11.6	90.7	....	170	168	50
1,000	73.4	24	8.4	13.2	89.8	....	168	168	50
1,100	82.2	25	9.6	13.7	89.6	....	170	170	50
1,200	90.0	25	10.5	13.7	89.6	....	170	170	50
1,300	96.3	27	12.2	14.8	88.7	....	168	168	50
1,400	101.8	30	14.6	16.4	87.4	....	170	170	50
1,500	105.8	31	16.2	17.0	86.7	....	170	170	50
1,600	108.0	32	17.9	17.6	85.8	....	175	175	50

Length of brake arm, 21 inches. Kind of oil used, U. S. Spec. 2-23B. Average barometer, 28.62 in. Hg.

ONE HOUR FUEL AND OIL CONSUMPTION RUN.

Elapsed time (minutes).	R. P. M. by counter.	Actual. Brake load (lbs.).	Actual. B. H. P.	Corr. H. P.	B. M. E. P. (lbs. per sq. in.).	Water temp. °F. In.	Water temp. °F. Out.	Oil press. (lbs. per sq. in.).	Carb. air temp. (°F.).	Man. vac. in. Hg.	Carb. vac. in. Hg.	Mix.[1] cont. position.	Gas. cons. Scale reading (lbs.).	Gas. cons. Lbs. per hp. hr.	Oil cons. Lbs. per hr.	Oil cons. Lbs. per hp. hr.
0.......	....	207	....	....	....	153	168	60	54	1.0	2.3	1.5	110.0	....	....	....
5.......	1,430	207	98.7	100.9	111.1	160	173	61	54	1.0	2.2	1.5	105.9	0.498	....	....
10......	1,426	207	98.4	100.6	111.1	162	174	62	54	1.0	2.2	1.5	102.0	0.476	....	....
15......	1,404	207	96.9	99.1	111.1	156	170	62	54	1.0	2.2	1.5	97.9	0.508	....	....
20......	1,410	207	97.3	99.5	111.1	155	169	62	54	1.0	2.2	1.5	93.9	0.494	....	....
25......	1,398	207	96.4	98.5	111.1	164	180	61	54	1.0	2.1	1.5	89.8	0.510	....	....
30......	1,396	207	96.3	98.4	111.1	156	170	61	55	1.1	2.2	1.5	85.8	0.499	....	....
35......	1,376	207	94.9	97.0	111.1	156	169	62	56	1.0	2.2	1.5	82.0	0.481	....	....
40......	1,384	206	95.0	97.1	110.5	159	174	62	56	1.0	2.1	1.5	78.2	0.480	....	....
45......	1,392	206	95.6	97.7	110.5	155	169	62	54	1.1	2.2	1.5	74.3	0.490	....	....
50......	1,386	206	95.2	97.3	110.5	154	168	62	55	1.1	2.2	1.5	70.2	0.517	....	....
55......	1,388	206	95.3	97.4	110.5	156	170	62	56	1.1	2.2	1.5	66.7	0.441	....	....
60......	1,388	206	95.3	97.4	110.5	162	174	62	56	1.1	2.2	1.5	62.8	0.491	2.2	....

AVERAGE RESULTS FOR ONE HOUR.

	1,398	206.6	96.3	98.5	111.0	158	171	62	55	1.0	2.2	1.5	47.2[2]	0.490	2.2	0.0228

[1] The mixture control was full rich at 3.2 and full lean at 1.2.
[2] Total for one hour.

Data for all runs: Length of brake arm, 21 inches. Kind of oil, U. S. Spec. 2-23-B. Fuel used (spec. grav.), 0.710 at 15° C. Average barometer, 29.27 in. Hg.

WATER-PUMP CAPACITY RUN.

Revolutions per minute.	Pounds per 15 seconds.	[1] Gallons per minute.	Revolutions per minute.	Pounds per 15 seconds.	[1] Gallons per minute.
800....................................	26.5	13.1	1,300....................................	41.75	20.6
	26.5	13.1		42.00	20.7
900....................................	29.25	14.4	1,400....................................	44.50	21.9
	28.50	14.0		44.75	22.0
1,000....................................	33.50	16.5	1,500....................................	48.50	23.9
	33.75	16.6		47.75	23.5
1,100....................................	36.60	18.0	1,600....................................	51.00	25.1
	36.00	17.7		50.50	24.9
1,200....................................	39.25	19.3			
	37.50	18.5			

[1] Water temperature was 170° F.; 8.12 pounds of water per gallon at 170° F.

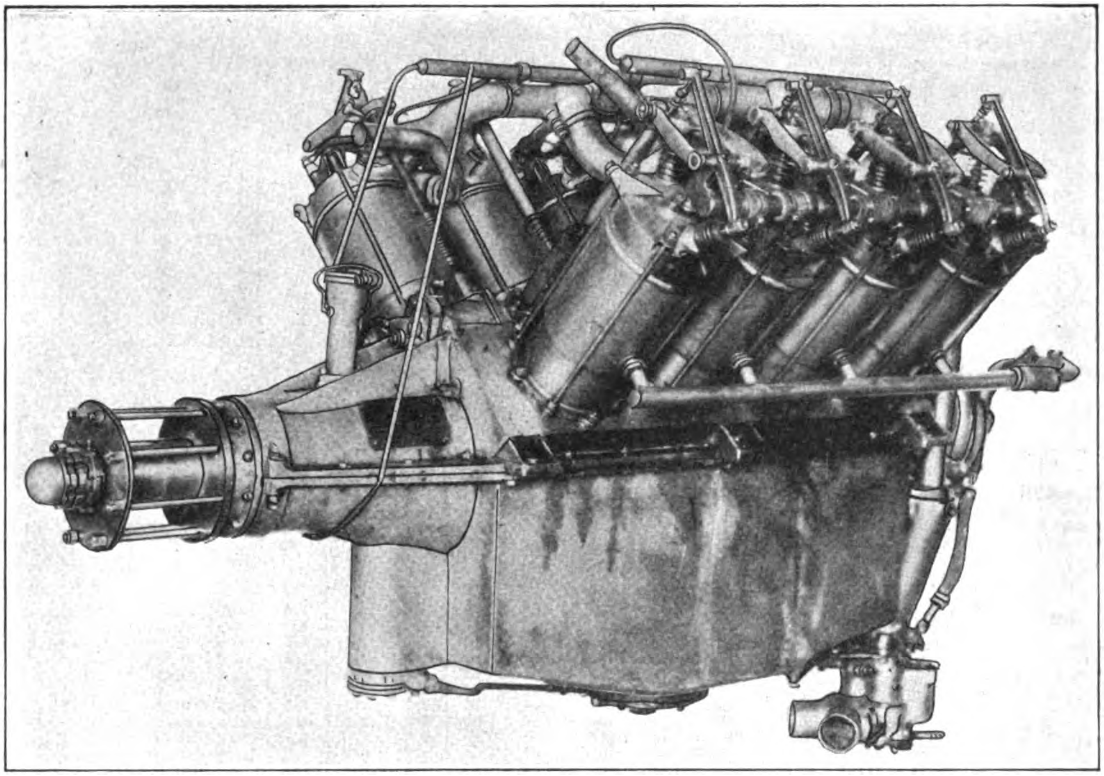


FIG. 1.—Three-quarter front view.

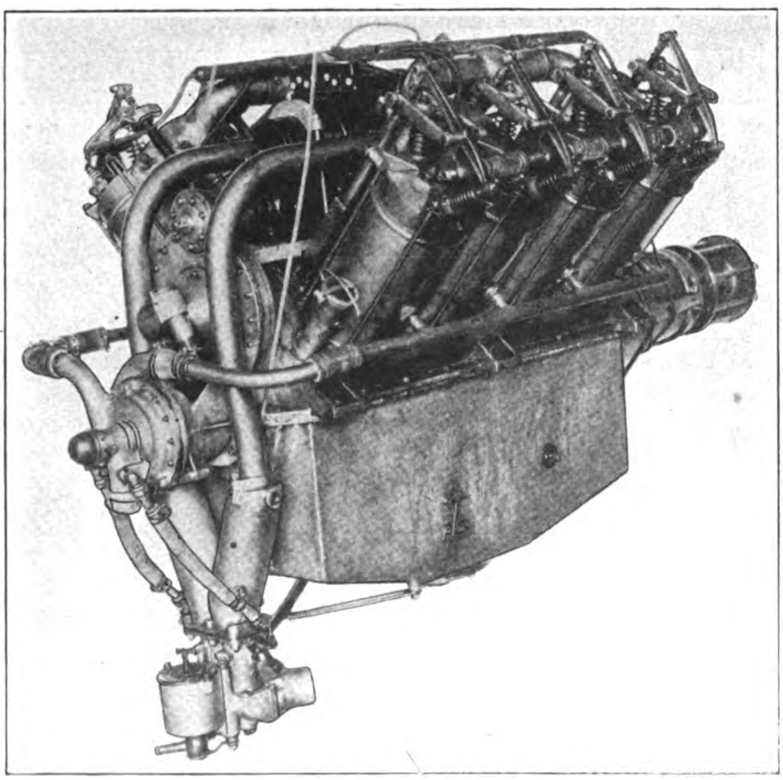


FIG. 2—Three-quarter rear view.

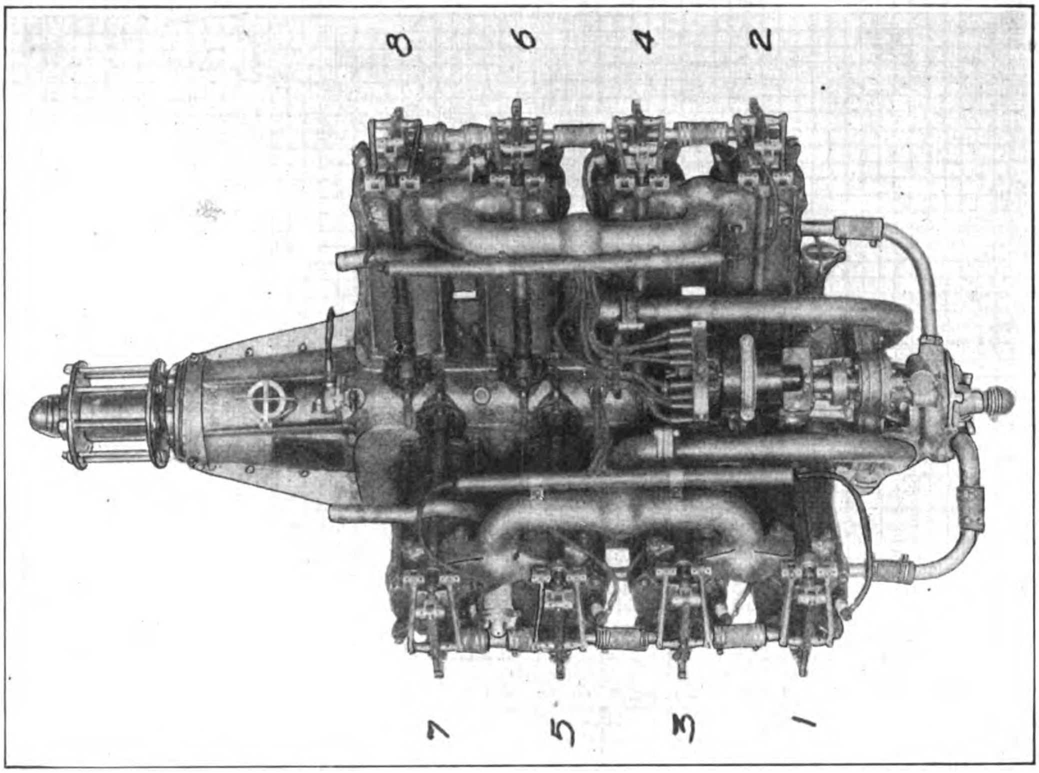


FIG. 3--Top view with cylinder numbers.

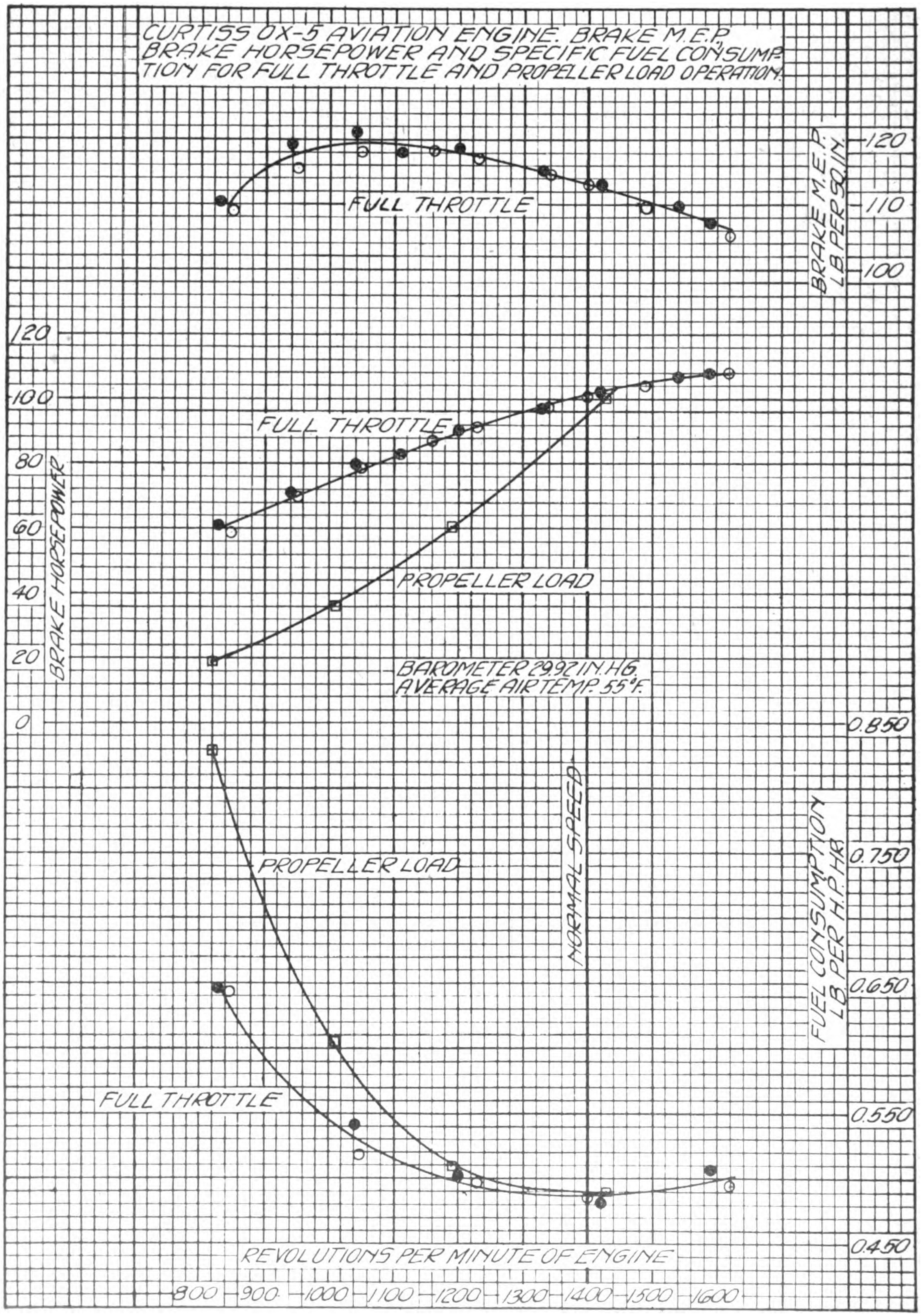

CURTISS OX-5 AVIATION ENGINE. BRAKE M.E.P. BRAKE HORSEPOWER AND SPECIFIC FUEL CONSUMPTION FOR FULL THROTTLE AND PROPELLER LOAD OPERATION.
FULL THROTTLE
BRAKE M.E.P. LB PER SQ. IN.
120
110
100
BRAKE HORSEPOWER
120
100
80
60
40
20
0
FULL THROTTLE
PROPELLER LOAD
BAROMETER 29.92 IN. HG.
AVERAGE AIR TEMP. 55°F.
NORMAL SPEED
PROPELLER LOAD
FULL THROTTLE
FUEL CONSUMPTION LB PER H.P. HR.
0.850
0.750
0.650
0.550
0.450
REVOLUTIONS PER MINUTE OF ENGINE
800
900
1000
1100
1200
1300
1400
1500
1600

FIGURE 4.

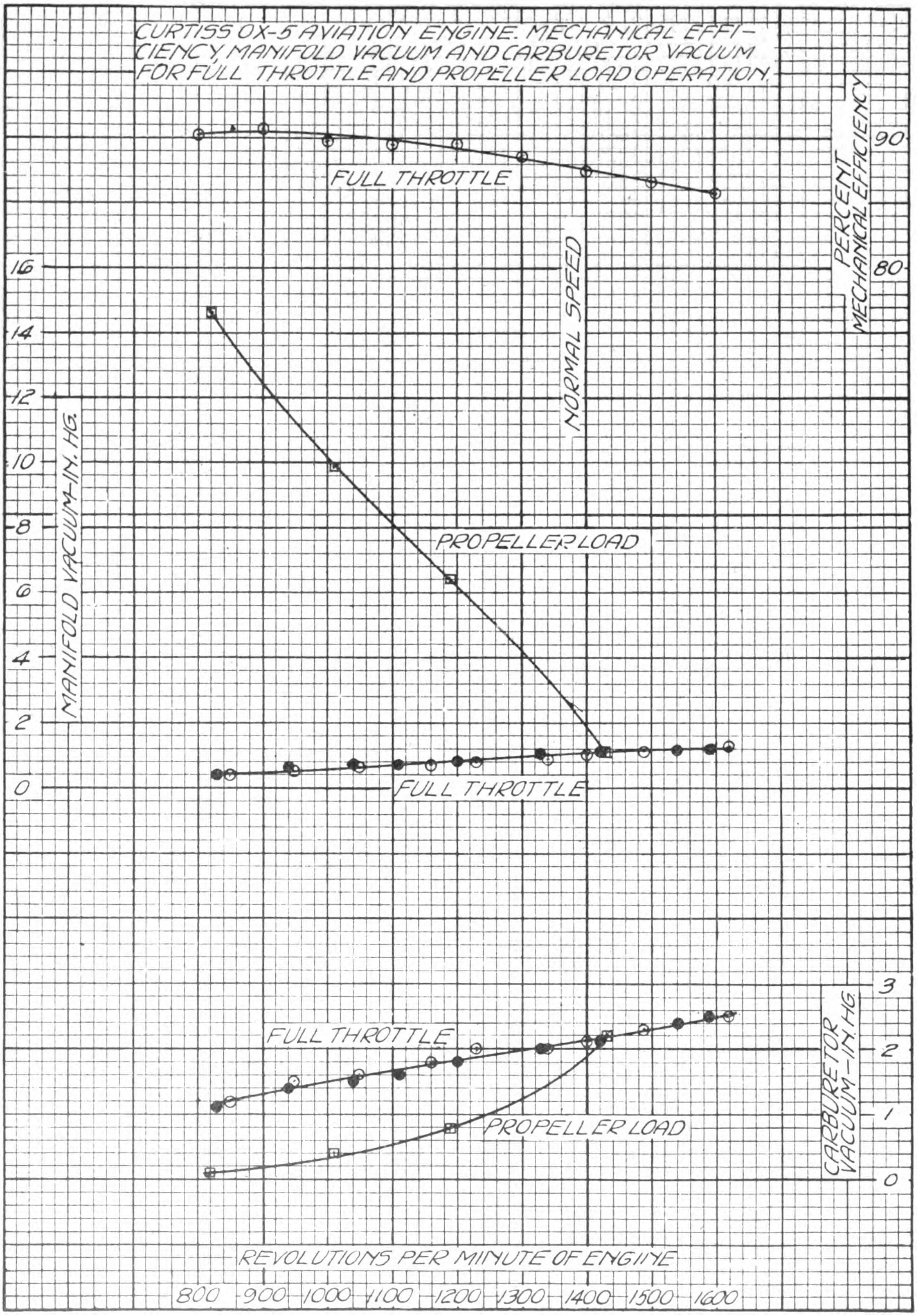

CURTISS OX-5 AVIATION ENGINE. MECHANICAL EFFICIENCY, MANIFOLD VACUUM AND CARBURETOR VACUUM FOR FULL THROTTLE AND PROPELLER LOAD OPERATION.
FULL THROTTLE
PERCENT MECHANICAL EFFICIENCY
90
80
NORMAL SPEED
16
14
12
10
8
6
4
2
0
MANIFOLD VACUUM-IN. HG.
PROPELLER LOAD
FULL THROTTLE
FULL THROTTLE
PROPELLER LOAD
CARBURETOR VACUUM-IN. HG.
3
2
1
0
REVOLUTIONS PER MINUTE OF ENGINE
800
900
1000
1100
1200
1300
1400
1500
1600

FIGURE 5.

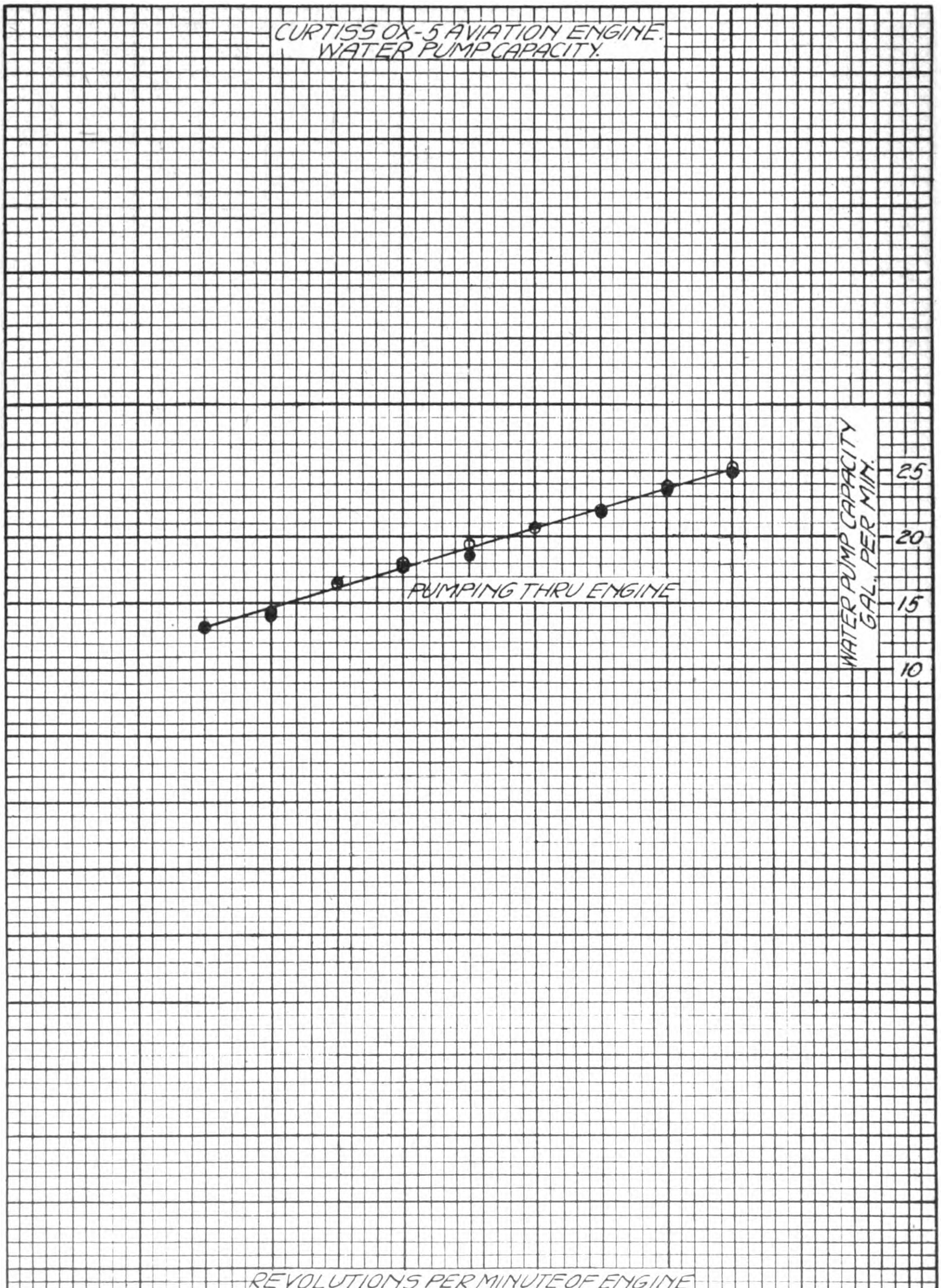

CURTISS OX-5 AVIATION ENGINE.
WATER PUMP CAPACITY.
PUMPING THRU ENGINE
WATER PUMP CAPACITY
GAL. PER MIN.
25
20
15
10
REVOLUTIONS PER MINUTE OF ENGINE
800
900
1000
1100
1200
1300
1400
1500
1600

FIGURE 6.

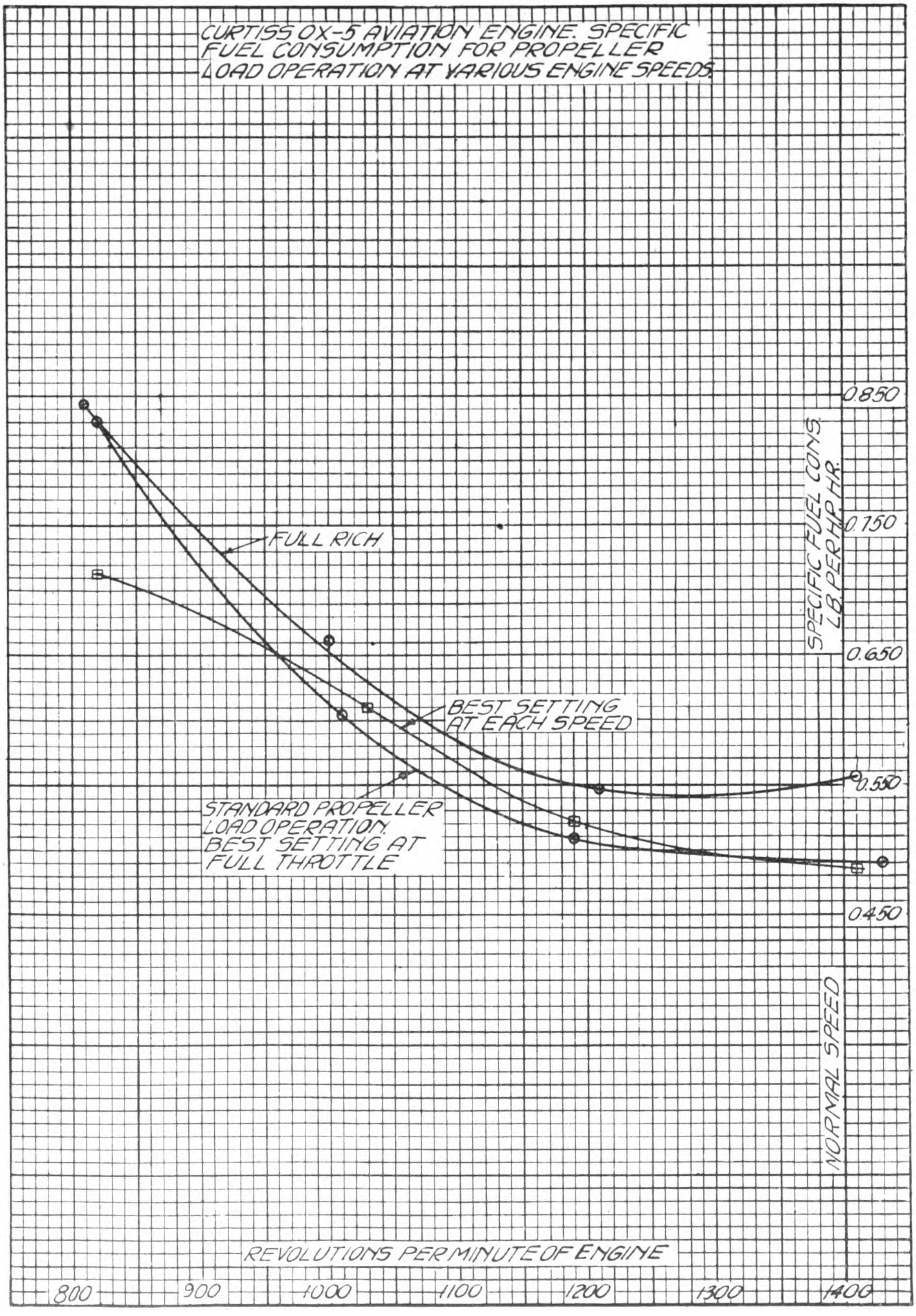
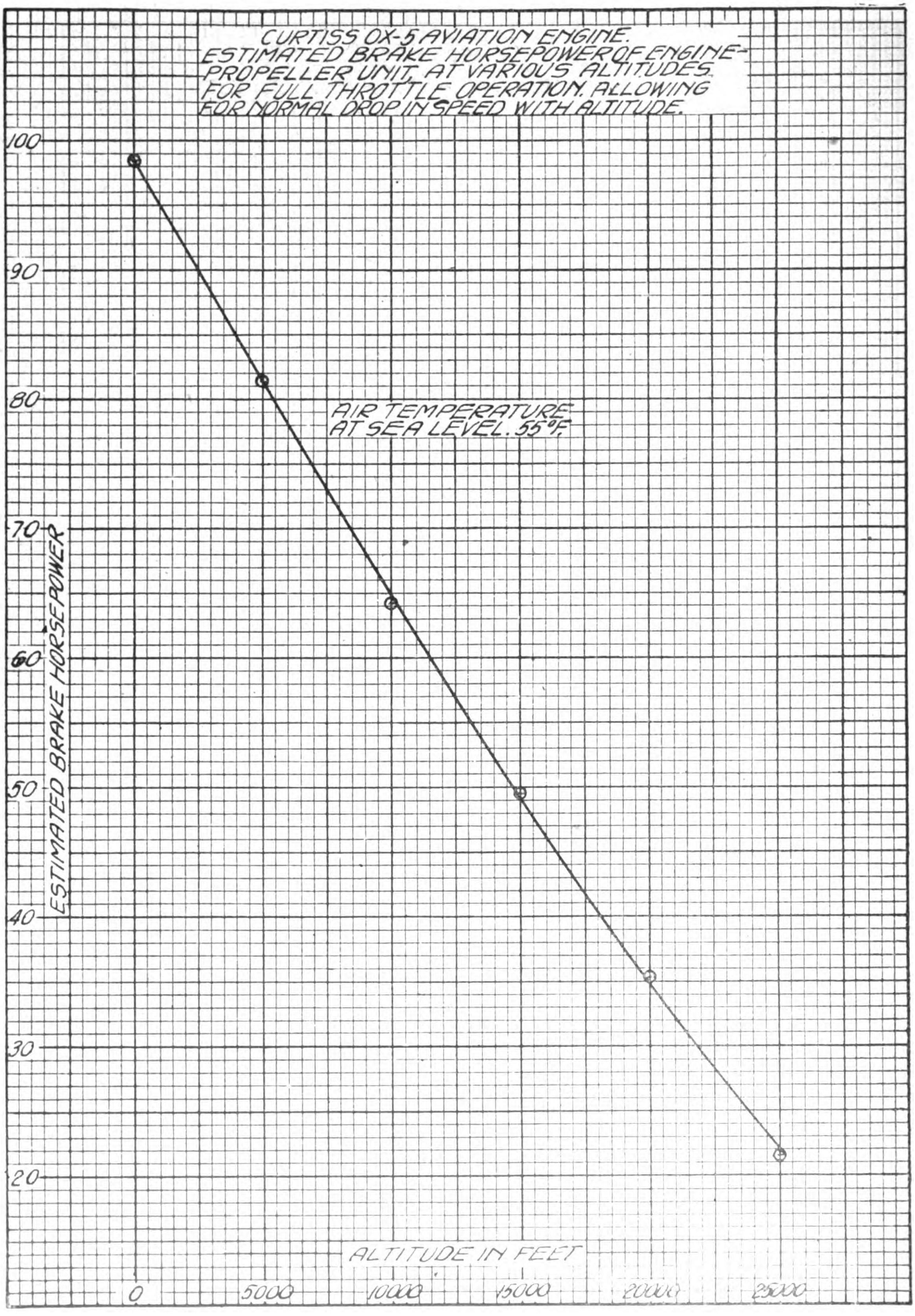

CURTISS OX-5 AVIATION ENGINE. SPECIFIC FUEL CONSUMPTION FOR PROPELLER LOAD OPERATION AT VARIOUS ENGINE SPEEDS.
FULL RICH
BEST SETTING AT EACH SPEED
STANDARD PROPELLER LOAD OPERATION. BEST SETTING AT FULL THROTTLE
SPECIFIC FUEL CONS. LB. PER H.P. HR.
0.850
0.750
0.650
0.550
0.450
NORMAL SPEED
REVOLUTIONS PER MINUTE OF ENGINE
800
900
1000
1100
1200
1300
1400

FIGURE 7.



CURTISS OX-5 AVIATION ENGINE.
ESTIMATED BRAKE HORSEPOWER OF ENGINE-PROPELLER UNIT AT VARIOUS ALTITUDES FOR FULL THROTTLE OPERATION. ALLOWING FOR NORMAL DROP IN SPEED WITH ALTITUDE.
AIR TEMPERATURE AT SEA LEVEL. 55°F.
ESTIMATED BRAKE HORSE POWER
100
90
80
70
60
50
40
30
20
ALTITUDE IN FEET
0
5000
10000
15000
20000
25000

FIGURE 8.

File D 11.2/27

McCOOK FIELD REPORT, SERIAL No. 1949

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | September 1, 1922 | No. 374

INTERIOR CORROSION OF STEEL STRUTS AND ITS PREVENTION

(MATERIAL SECTION REPORT NO. 172)

▽

Prepared by V. M. Wade
Engineering Division, Air Service
McCook Field, Dayton, Ohio
June 5, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INTERIOR CORROSION OF STEEL STRUT TUBING AND ITS PREVENTION.

PURPOSE.

To investigate the necessity of protecting from corrosion the interior of airplane parts manufactured from steel tubing, and also to develop a suitable method for cleaning and coating the interior of these parts.

CONCLUSIONS.

It was found to be very desirable to protect the interior of steel tubing.

The inside of the tubing should be thoroughly cleaned before any protective coating is applied. The best method is pickling, followed by immersion of the part in a weak soda solution, thoroughly rinsing in hot water and drying with an air blast. The pickling solution recommended is a 5 per cent sulphuric acid, steam heated. This method can only be followed when both ends of the tube are open, and should be used only when other methods have failed to give a clear interior surface. When it is impracticable to pickle and the ends are open, the use of a wire brush is recommended. The tubing should be thoroughly cleaned and dried before it is assembled into the structure.

After cleaning, the inside of the tube should be protected by a liquid primer of the following composition:

	Per cent.
Liquid	45
Pigment	55

The following formula is recommended:

	Per cent.
Liquid:	
Raw linseed oil	70
Drier and turpentine	30
Pigment: Indian red (90 per cent Fe_2O_3).	100

This liquid should be applied after all welding, brazing, and other operations involved in the fabrication of the part from the tubing.

When the ends are closed, the pigment mixture should be forced in under air pressure and allowed to drain from the other end of the tube.

The weight of one coat of the metal primer is less than 1 ounce per square foot.

Zinc plating gave the best results as far as durability alone is concerned, but in many cases zinc can not be applied to the interior of tubular parts.

When the tubes are zinc plated on the exterior, the interior should be thoroughly washed with warm water, drained, and dried with an air blast after plating.

Such compounds as "No-Oxide A" and "Rust Veto Heavy" gave good results, but were too thick to apply to small tubular members.

MATERIAL.

The following material was used as coatings for the inside of metal struts:

1. Zinc plating.................Chemistry branch.
2. Linseed oil primer............Chemistry branch.
   - Liquid.....................45 per cent.
   - Pigment....................55 per cent.
     - Liquid:
       - Raw linseed oil.....70 per cent.
       - Drier and turpentine. 30 per cent.
     - Pigment: Indian Red (90 per cent Fe_2O_3).......100 per cent.
3. Varnish primer...............Chemistry branch.
   - Liquid.....................45 per cent.
   - Pigment....................55 per cent.
     - Liquid:
       - Spar varnish.........70 per cent.
       - Drier and turpentine. 30 per cent.
     - Pigment: Indian Red (90 per cent Fe_2O_3).......100 per cent.
4. Rust preventive V. D. 1536.....Patton Pitcairn Paint Co., Milwaukee, Wis.
5. Blue steel wire lacquer.........Pratt & Lambert (inc.), Buffalo, N. Y.
6. Valspar varnish...............Valentine & Co., New York City.
7. Aluminum enamel............Valentine & Co., New York City.
8. Baking varnish V-811...........Lowe Bros., Dayton, Ohio.
9. No-Oxide A.......................Dearborn Chemical Co., Chicago, Ill.
10. Rust Veto Heavy...............E. F. Houghton & Co., Philadelphia, Pa.

METAL.

1. Steel struts from stock at McCook Field, Dayton, Ohio.

METHOD OF PROCEDURE.

Coated and uncoated samples of tubing were exposed to atmospheric conditions and the rate of corrosion was noted. The tubing was first cleaned, washed and dried, and then coated on the outside with zinc plating, excepting No. C 1 and 2. They were exposed uncoated both inside and outside.

The coatings were applied by pouring them in the tubes and then draining in an upright position.

The following methods and solutions for cleaning the inside of the tubes were tried:

a. Vasoline oil.................. 4 parts.
Turpentine.................. 1 part.
Naphtha..................... 1 part.
Rubbed with a brush and washed with benzol and then dried thoroughly.

b. Kerosene.................... 2 parts.
Sperm oil..................... 1 part.
Turpentine.................. 1 part.
Acetone..................... 1 part.
Blown dry with air at 120 pounds pressure.

c. Stannic chloride............ 100 g.
Water....................... 1,000 c. c.
Tartaric acid................ 2 g.
Water....................... 1,000 c. c.

d. Immersed tubes in kerosene. Immersed in benzol, drained, and then dried thoroughly with air blast at 120 pounds pressure.

e. Immersed tubes in dilute sulphuric acid (10 per cent solution), washed with hot water, and dried.

f. Immersed tubes in 50 per cent hydrochloric acid and 10 per cent formaldehyde, washed and dried.

g. Immersed tubes in steam heated 5 per cent sulphuric acid, washed in weak soda solution, thoroughly rinsed in hot water, and dried with air blast.

Grease spots were removed with commercial benzol. Dirt was removed with hot water and then blown dry with an air blast.

RESULTS.

See Tables 1 and 2, also figures 1, 2, and 3.

DISCUSSION OF RESULTS.

Organic coatings will not adhere to greasy, dirty, or rusty metal surfaces, but will flow around the uncleaned spots, which later become starting points for rust. There may also be a progression of the corrosion from the rust under the coating, therefore this rust must be removed to insure good results.

It is very difficult to obtain tubing that is not rusted or dirty when received, because in shipping some moisture collects on the inside of the tubing. It is practically useless to coat over this rust, and some method of cleaning the inside of the tubing before coating should be used. The grease should first be removed with either benzol (90 per cent) or such commercial cleansers as Oakite, etc., then the dirt and rust can best be removed in a hot 5 per cent sulphuric-acid solution. (This method should be followed only by those who are experienced in pickling steel.[1] The tube should then be washed with hot water and thoroughly dried by means of an air blast of about 100 pounds pressure. This should be done before the ends of the tubes are closed. After the tubes are closed, a hole about one-eighth of an inch in diameter should be left in each end of the tubing so that the coating may be poured in and drained out. A coating of an iron oxide metal primer (B–1) will insure protection to the inside of the tubing. Where possible the inside of the tubing should be brushed with a wire brush. This will help to remove most of the rust.

The primer is recommended in preference to the grease compounds such as No-Oxide A and Rust Veto Heavy because they were too thick to apply through a one-eighth inch hole. It might be suggested that these compounds be thinned, but previous exposure tests have indicated that the thin coatings do not give as great a protection as do the thick ones.

The cleaning compounds, such as "a," "b," and "c" are rather expensive and the results were no better than those obtained by use of benzol and sulphuric-acid cleaning solutions. While the iron oxide primer in the series of tests just competed gave the best results, other experimenters have found that a primer made of red lead or graphite will give results as good as iron oxide. These pigments gave good results both for adhesion and for minimum deterioration of film and minimum corrosion underneath the film. It is interesting to note that in the tests conducted by the paint manufacturers' association,[2] the vehicle recommended was raw linseed oil similar to that used in the iron oxide primer.

The pigment used in the iron oxide primer is Indian red. Indian red is a natural hematite or Persian Gulf ore. Only those ores having the proper shade are selected and termed "Indian red." The term "Indian red" is also applied sometimes to artificial iron oxides made by calcining copperas. These pigments generally contain from 90 to 95 per cent oxide of iron, with varying percentages of silica. The natural iron oxides made from hematite ores, some of which are termed "bright red oxide" and "Indian red," have a gravity of 3.5 to 5.2 and grind in about 20 to 25 per cent of oil. The natural iron oxides make valuable body pigments for inhibitive paints.

Though graphite gave good results in the tests conducted by the paint manufacturers' association, there are some objections to its use as an inhibitor. There are two forms of graphite, namely, the natural and the artificial. These contain varying amounts of carbon mixed with silica and sometimes iron oxide. The percentage of carbon is usually over 90.

Both forms of graphite have been used extensively as coatings for steel and iron, but, due to the excessive spreading of the paint, the paint film is very thin and sometimes does not afford as great a protection as is desired. For this reason graphite paints are mixed with heavier pigments. However, it is not considered a good inhibitor on account of the ease with which it conducts electric currents.

Red lead is a very heavy, brilliant red pigment, and is made by further oxidizing litharge (lead oxide). It, along with iron oxide, is considered one of the best pigments known for the protection of steel and iron. The one objection to red lead is the stiffness of the resulting paint. This would mean that the red-lead paint is very thick and heavy, which would be an objection to the use of red lead in aircraft construction.

[1] The tubes should remain in the pickling solution for about 10 minutes.

[2] Corrosion and Preservation of Iron and Steel, by Cushman and Gardner.

Table No. 1.—*Interior coatings for metal struts after 401 days exposure.*

No.	Name and description.	Company.	Exposed.	June 4, 1921		September 1, 1921		May 12, 1922	
				Outside.	Inside.	Outside.	Inside.	Outside.	Inside.
A1–o	Zinc plating	Chemistry branch	April 6, 1921	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
A2–c	do	do	do	O. K.	O. K.	O. K.	Sl cor.	O. K.	3%
B1–o	Raw linseed oil and Indian red	do	do	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
B2–c	do	do	do	O. K.	O. K.	O. K.	Sl cor.	O. K.	5%
C1–o	No coating	do	do	100	90	....	100	....	....
C2–c	do	do	do	100	95	....	100	....	....
D1–o	Rust preventive V. D. 1536	Patton - Pitcairn, Milwaukee, Wis.	do	O. K.	O. K.	O. K.	O. K.	O. K.	10%
D2–c	do	do	do	O. K.	3%	O. K.	10%	O. K.	40%
E1–o	Spar varnish and Indian red	Chemistry branch	do	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
E2–c	do	do	do	O. K.	O. K.	O. K.	10%	30%	40%
F1–o	Blue lacquer No. 3729	Pratt & Lambert Co., Buffalo, N. Y.	do	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
F2–c	do	do	do	O. K.	2%	O. K.	20%	O. K.	50%
G1–o	Valspar varnish	Valentine & Co., New York City.	do	O. K.	O. K.	O. K.	O. K.	O. K.	5%
G2–c	do	do	do	O. K.	O. K.	O. K.	5%	O. K.	10%

Note.—o=open; c=closed.
Outside zinc plated except C1 and 2.
The closed tubes were saturated with salt water, then closed.
The increased corrosion of E2–c, spar varnish and Indian red, over that of G2–c, straight spar varnish, was due to the fact that the tube E2–c blew off the rack during a storm and was not replaced until after corrosion had started.

Table No. 2.—*Interior coatings for metal struts after 254 days' exposure.*

No.	Name and description.	Company.	Exposed.	October 30, 1921		May 12, 1922		Remarks.
				Outside.	Inside.	Outside.	Inside.	
H1–c	Aluminum enamel	Valentine & Co., New York City.	Sept. 1, 1921	O. K.	O. K.	O. K.	5%	200 c. c. water inside at time of inspection.
H2–o	do	do	do	O. K.	O. K.	O. K.	50%	
J1–c	Baking varnish V-811 (1 hour at 250° F.).	Lowe Bros. Co., Dayton, Ohio.	do	O. K.	O. K.	O. K.	5%	
J2–o	do	do	do	O. K.	O. K.	30%	7%	
K1–c	No-oxide A	Dearborn Chemical Co., Chicago, Ill.	do	O. K.	O. K.	O. K.	O. K.	Coating too thick for small tubes.
K2–o	do	do	do	O. K.	O. K.	O. K.	O. K.	
L1–c	Rust Veto Heavy	E. F. Houghton & Co., Philadelphia, Pa.	do	O. K.	O. K.	O. K.	O. K.	Do.
L2–o	do	do	do	O. K.	O. K.	O. K.	O. K.	
......	No coating on inside; outside zinc plated.	Chemistry branch	do	O. K.	100	....	....	

Note.—o=open tube; c=closed tube.
All tubes were zinc plated on outside.
The closed tubes were saturated with salt water, then closed.

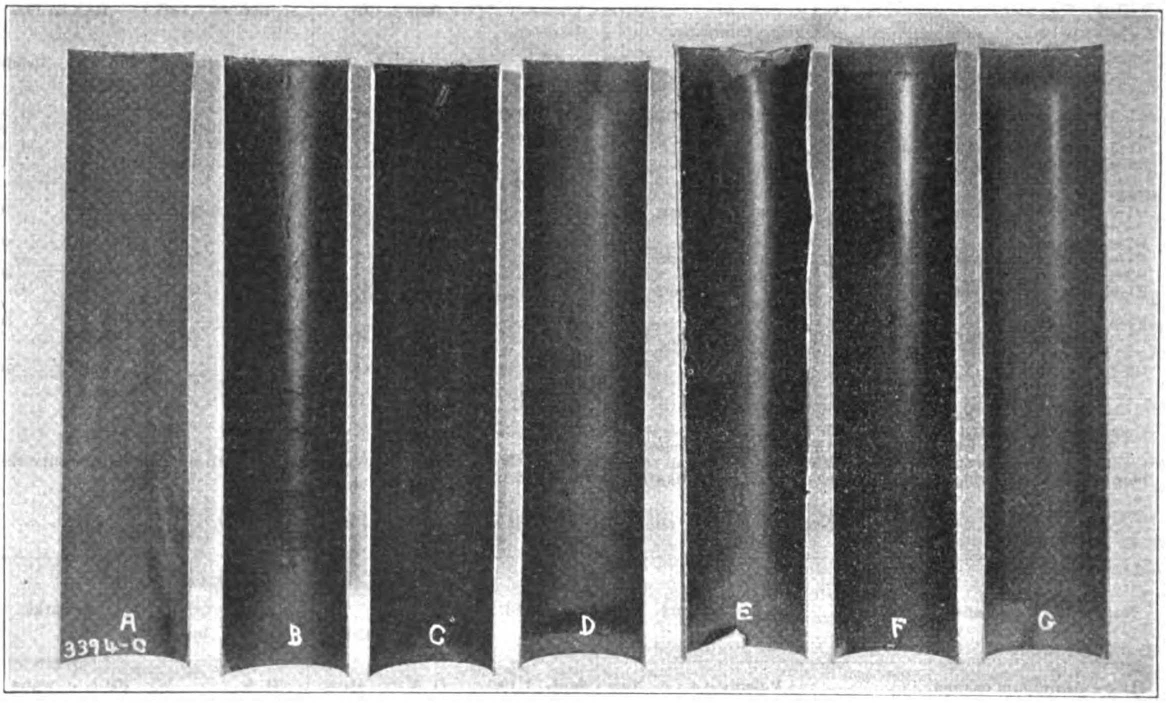


FIG. 1.—Section of metal tubing exposed 401 days. Open and exposed to the weather.

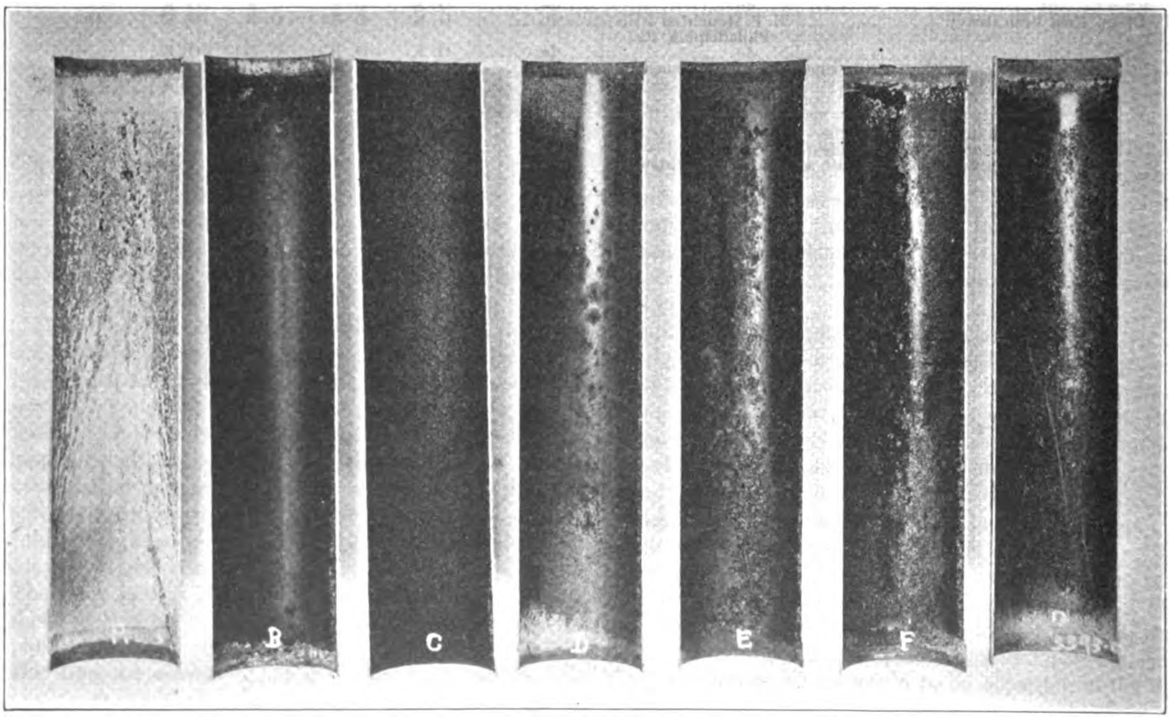


FIG. 2.—Section of metal tubing exposed 401 days. Closed and saturated with salt water solution.

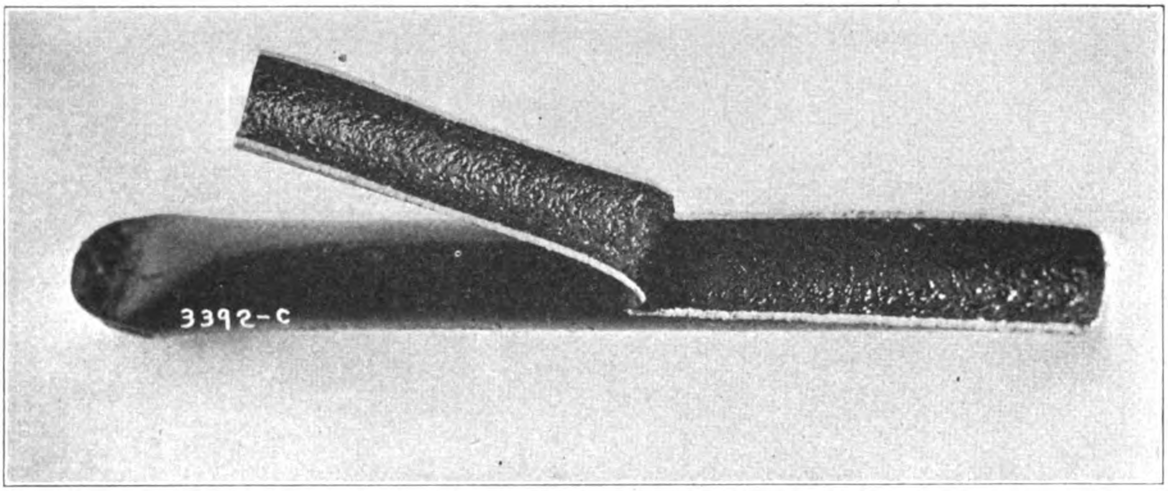


FIG. 3.—Service metal tubing. Outside coated. Inside uncoated. Showing the necessity of coating the interior.

File D 11.3/27

McCOOK FIELD REPORT, SERIAL No. 1934

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | October 15, 1922 | No. 375

CURVES FOR ESTIMATING THE FUEL CONSUMPTION OF AN AVIATION ENGINE ON THE BASIS OF PISTON DISPLACEMENT AND REVOLUTIONS PER MINUTE

(POWER PLANT SECTION REPORT)

▽

Prepared by C. F. Taylor
Engineering Division, Air Service
McCook Field, Dayton, Ohio
May 3, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE.—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

CURVES FOR ESTIMATING THE FUEL CONSUMPTION OF AN AVIATION ENGINE ON THE BASIS OF PISTON DISPLACEMENT AND REVOLUTION PER MINUTE.

The accompanying curves have been drawn for the purpose of determining the correct full throttle fuel consumption for normal types of water-cooled aviation engines when only the piston displacement and revolutions per minute are known.

These curves should be particularly useful in adjusting the carburetor of an engine whose normal power output has not been determined, or which is run in a fuselage or on a test stand not equipped for measuring power.

The assumptions used in making calculations for the curves are as follows:

Volumetric efficiency, 0.85.
Ratio of air to fuel, by weight, 15.
Barometer, 29.92 in. hg.
Atmospheric temperature, 60° F.

Using the above assumption, the equation for these curves is as follows:

$$F = N D \times .000075.$$

where:

F=fuel consumption, pounds per hour.
N=revolutions per minute of engine.
D=piston displacement, cubic inches.

It has been found that these curves agree very closely with results obtained with water-cooled aviation engines having a compression ratio between 5.0 and 5.5:1 and using normal carburetor settings.

These curves are also correct for the assumptions:

Volumetric efficiency, 0.80.
Ratio of air to fuel, 14.
Air density, pounds per cubic foot, 0.076.

For other assumptions of volumetric efficiency, air density and mixture ratio, the following formula may be used:

$$F = \frac{ENDd}{R} \times 0.0174$$

where:

E=Volumetric efficiency, expressed as a decimal.
R=Ratio of air to fuel by weight.
d=Air density, pounds per cubic foot.

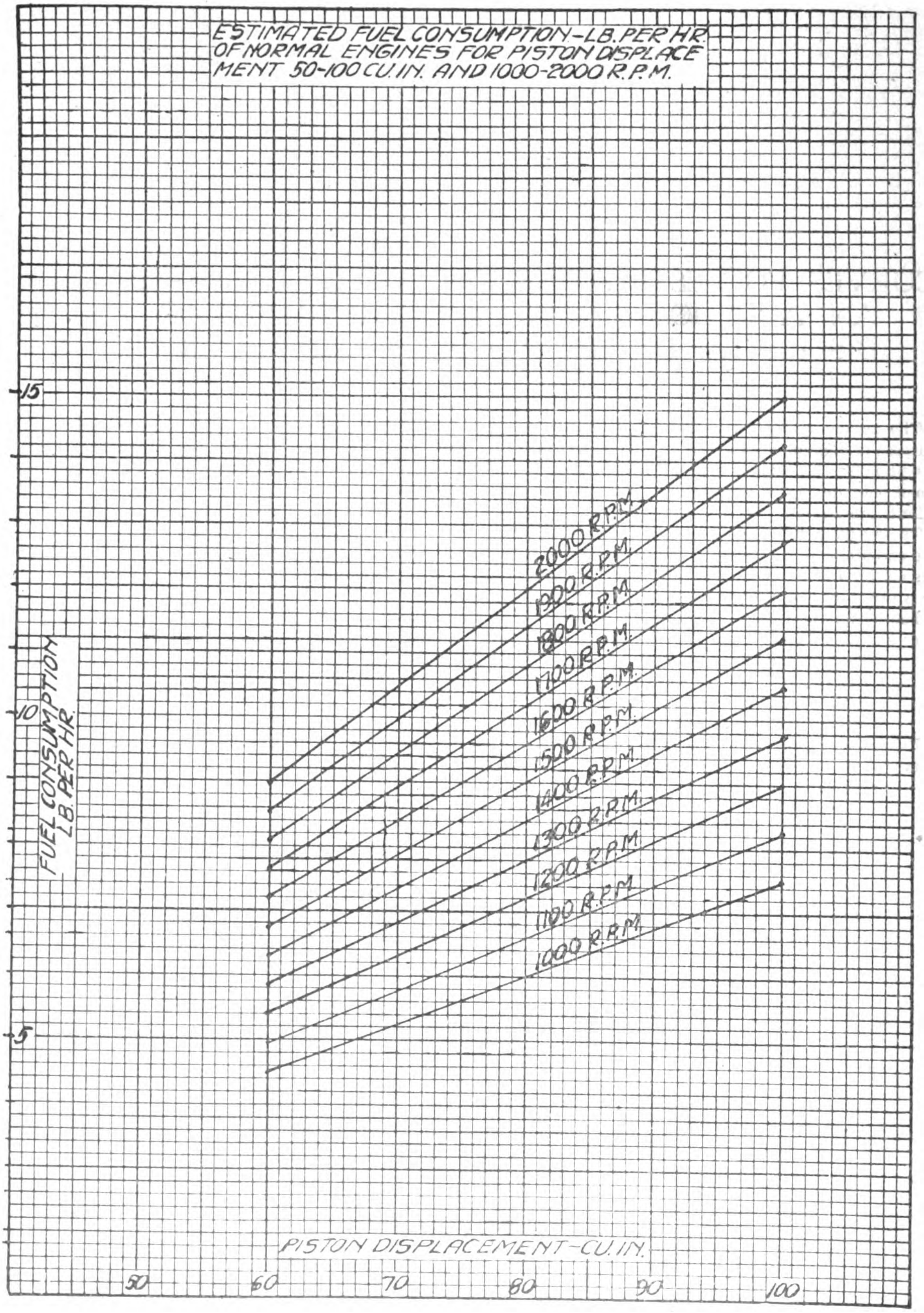
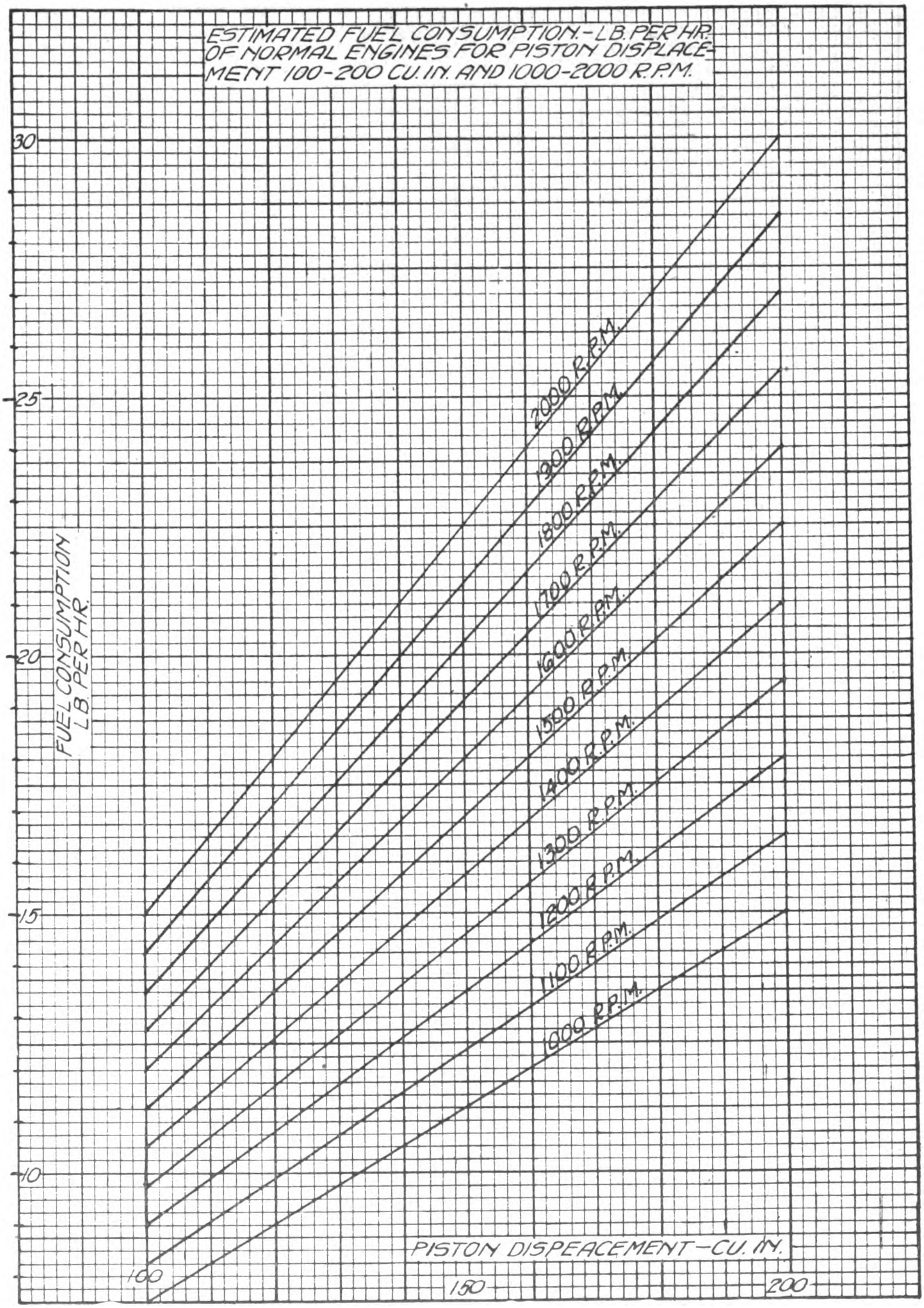

ESTIMATED FUEL CONSUMPTION-LB. PER HR. OF NORMAL ENGINES FOR PISTON DISPLACEMENT 50-100 CU. IN. AND 1000-2000 R.P.M.
FUEL CONSUMPTION LB. PER HR.
15
10
5
2000 R.P.M.
1900 R.P.M.
1800 R.P.M.
1700 R.P.M.
1600 R.P.M.
1500 R.P.M.
1400 R.P.M.
1300 R.P.M.
1200 R.P.M.
1100 R.P.M.
1000 R.P.M.
PISTON DISPLACEMENT-CU. IN.
50
60
70
80
90
100

Fig. 1.



ESTIMATED FUEL CONSUMPTION.-LB. PER HR. OF NORMAL ENGINES FOR PISTON DISPLACEMENT 100-200 CU. IN. AND 1000-2000 R.P.M.
FUEL CONSUMPTION LB. PER HR.
30
25
20
15
10
2000 R.P.M.
1900 R.P.M.
1800 R.P.M.
1700 R.P.M.
1600 R.P.M.
1500 R.P.M.
1400 R.P.M.
1300 R.P.M.
1200 R.P.M.
1100 R.P.M.
1000 R.P.M.
PISTON DISPEACEMENT-CU. IN.
100
150
200

Fig. 2.

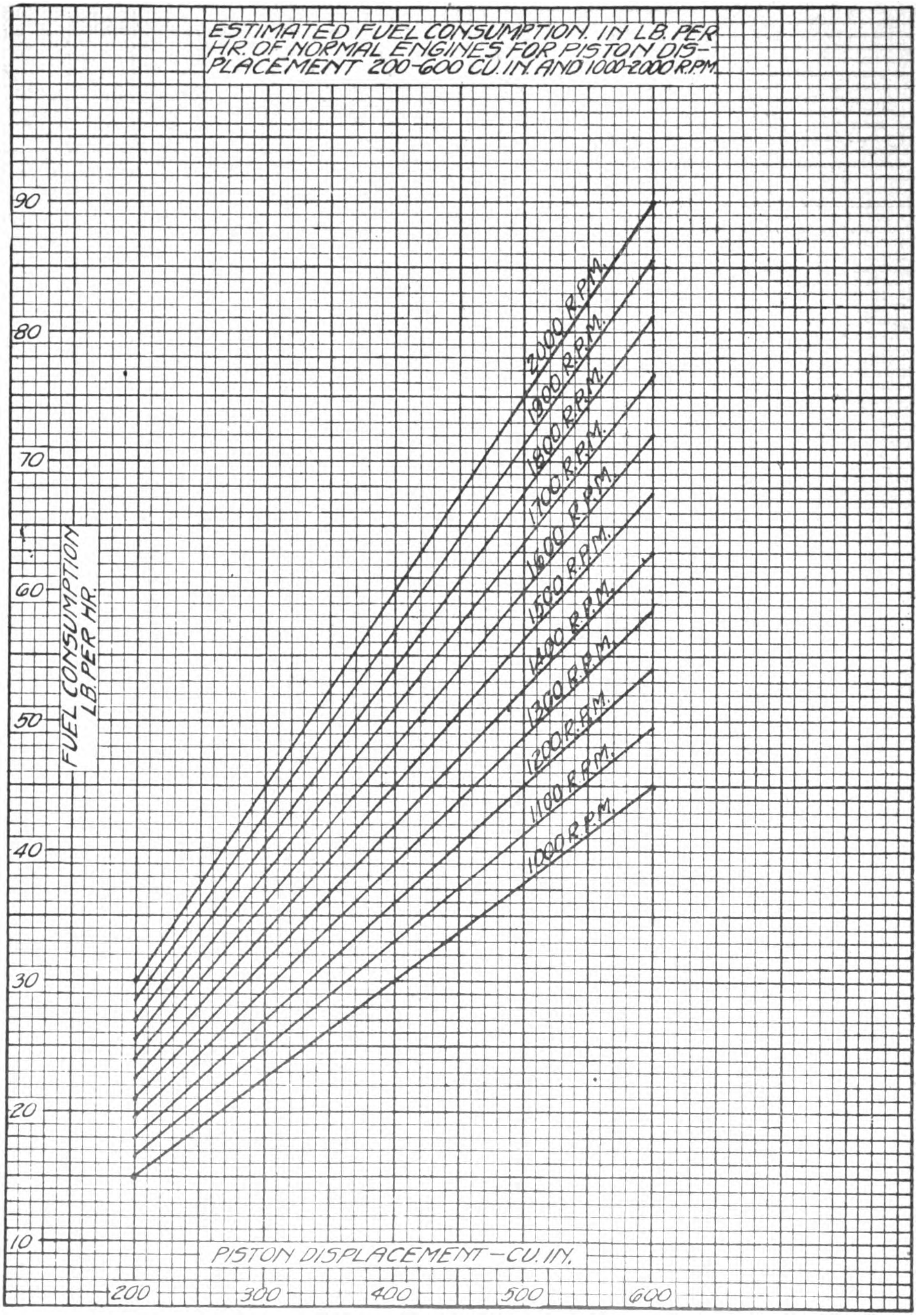

ESTIMATED FUEL CONSUMPTION IN LB. PER HR. OF NORMAL ENGINES FOR PISTON DISPLACEMENT 200-600 CU. IN. AND 1000-2000 R.P.M.
FUEL CONSUMPTION LB. PER HR.
PISTON DISPLACEMENT—CU. IN.
2000 R.P.M.
1900 R.P.M.
1800 R.P.M.
1700 R.P.M.
1600 R.P.M.
1500 R.P.M.
1400 R.P.M.
1300 R.P.M.
1200 R.P.M.
1100 R.P.M.
1000 R.P.M.
10
20
30
40
50
60
70
80
90
200
300
400
500
600

FIG. 3.

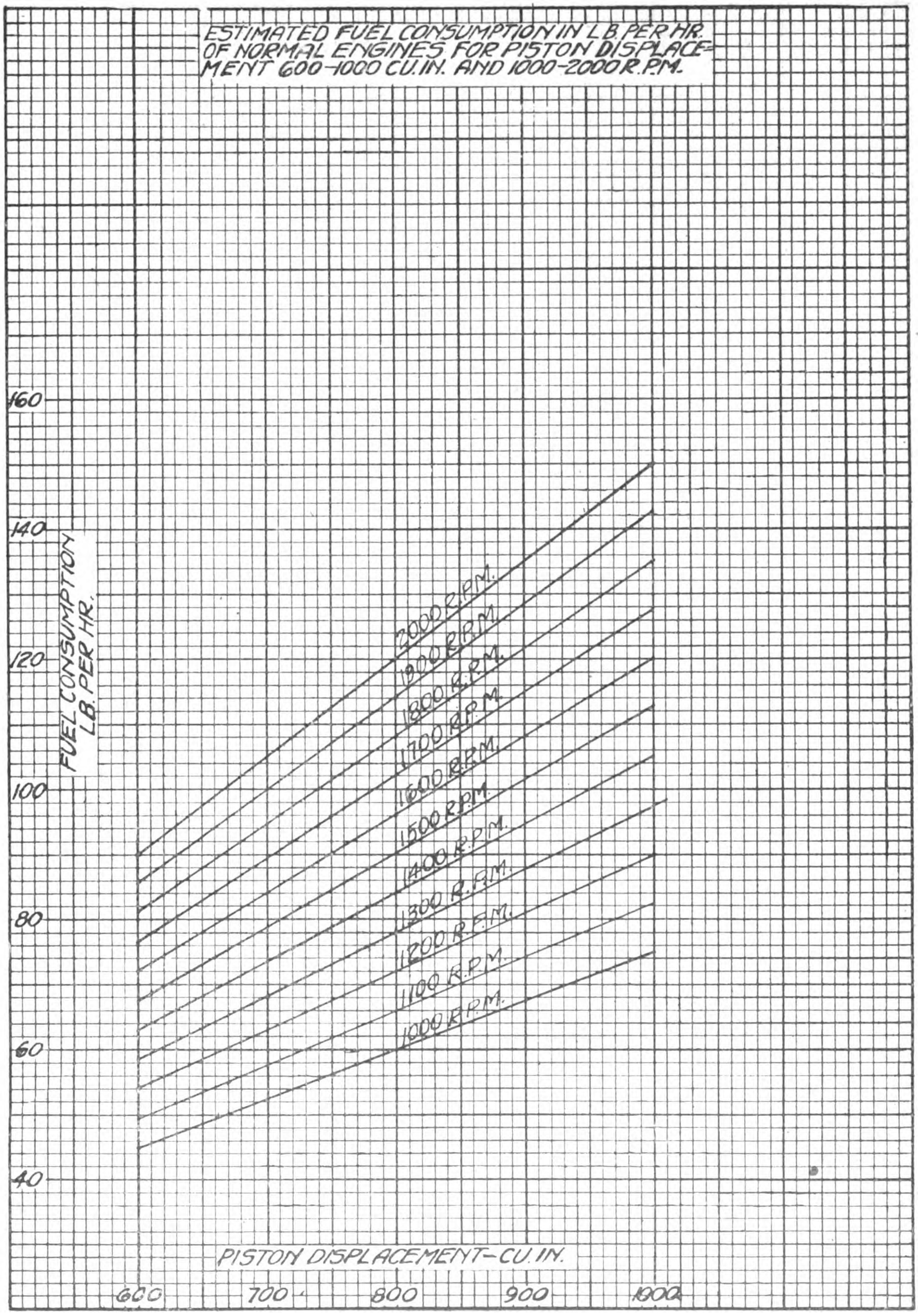

ESTIMATED FUEL CONSUMPTION IN L.B. PER HR. OF NORMAL ENGINES FOR PISTON DISPLACEMENT 600-1000 CU. IN. AND 1000-2000 R.P.M.
FUEL CONSUMPTION L.B. PER HR.
160
140
120
100
80
60
40
2000 R.P.M.
1900 R.P.M.
1800 R.P.M.
1700 R.P.M.
1600 R.P.M.
1500 R.P.M.
1400 R.P.M.
1300 R.P.M.
1200 R.P.M.
1100 R.P.M.
1000 R.P.M.
PISTON DISPLACEMENT-CU. IN.
600
700
800
900
1000

FIG. 4.

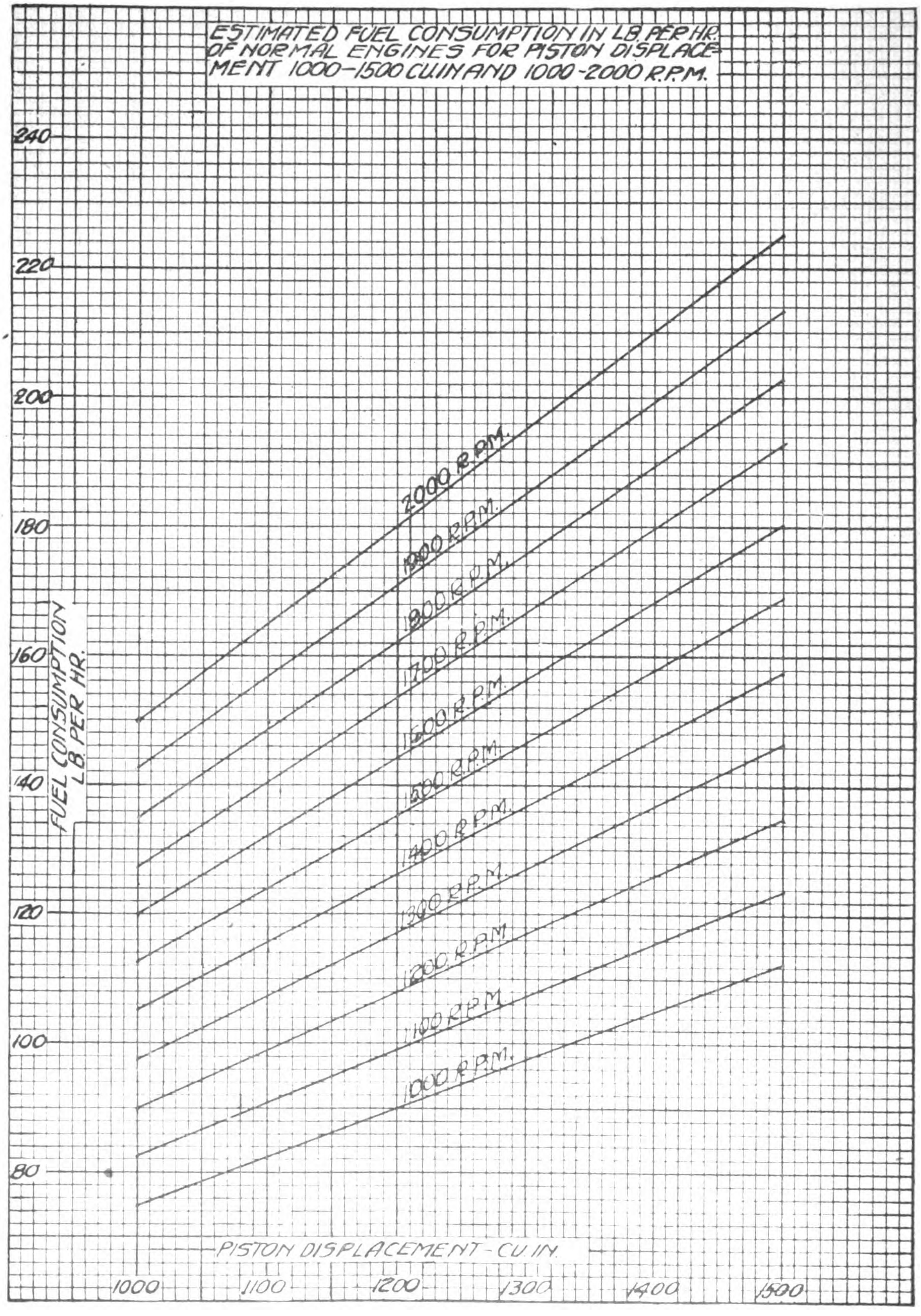

ESTIMATED FUEL CONSUMPTION IN LB. PER HR. OF NORMAL ENGINES FOR PISTON DISPLACEMENT 1000-1500 CU. IN. AND 1000-2000 R.P.M.
FUEL CONSUMPTION LB. PER HR.
240
220
200
180
160
140
120
100
80
2000 R.P.M.
1900 R.P.M.
1800 R.P.M.
1700 R.P.M.
1600 R.P.M.
1500 R.P.M.
1400 R.P.M.
1300 R.P.M.
1200 R.P.M.
1100 R.P.M.
1000 R.P.M.
PISTON DISPLACEMENT - CU. IN.
1000
1100
1200
1300
1400
1500

FIG. 5.

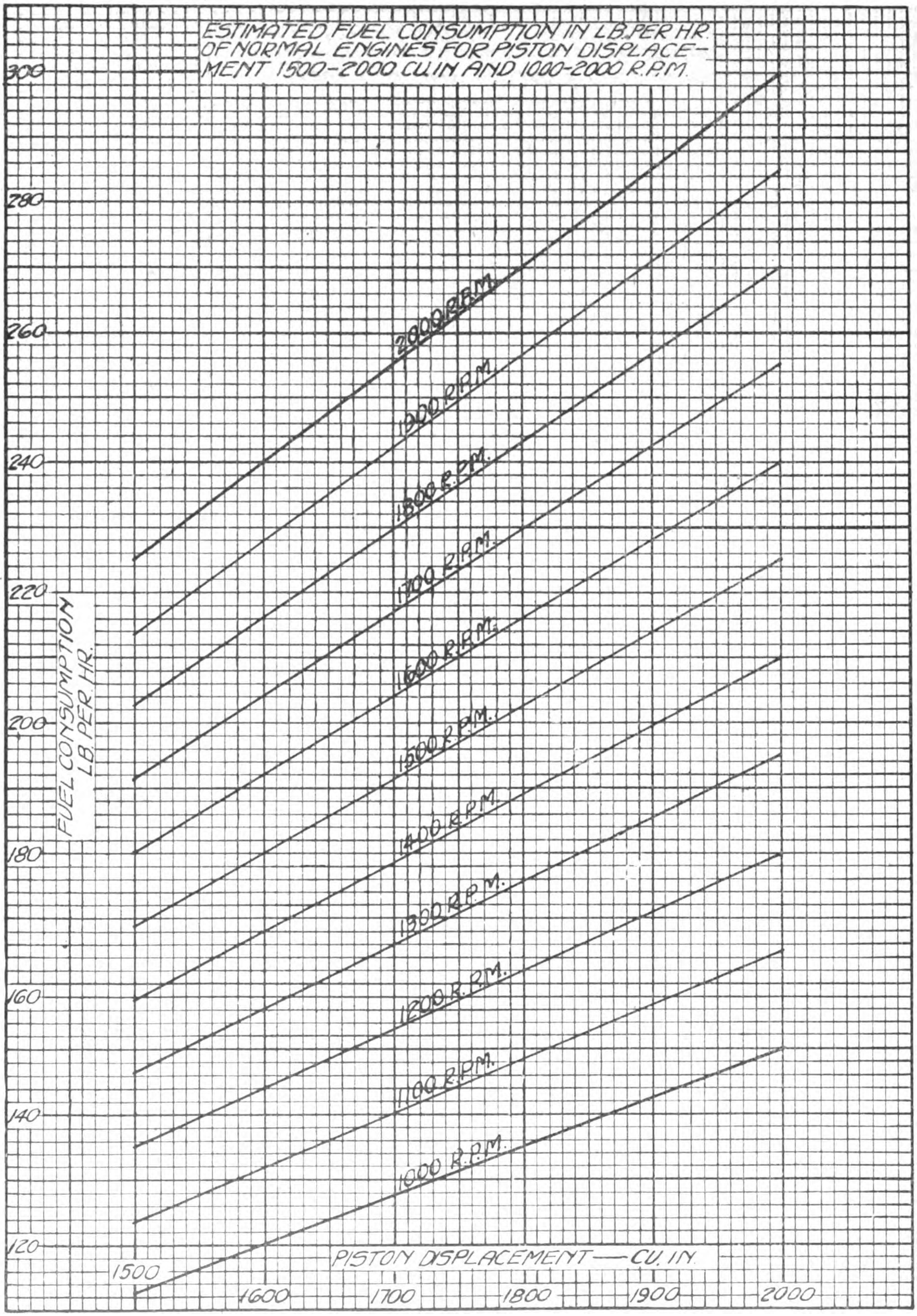

ESTIMATED FUEL CONSUMPTION IN LB. PER HR. OF NORMAL ENGINES FOR PISTON DISPLACEMENT 1500-2000 CU. IN. AND 1000-2000 R.P.M.
FUEL CONSUMPTION LB. PER HR.
PISTON DISPLACEMENT — CU. IN.
2000 R.P.M.
1900 R.P.M.
1800 R.P.M.
1700 R.P.M.
1600 R.P.M.
1500 R.P.M.
1400 R.P.M.
1300 R.P.M.
1200 R.P.M.
1100 R.P.M.
1000 R.P.M.
300
280
260
240
220
200
180
160
140
120
1500
1600
1700
1800
1900
2000

FIG. 6.

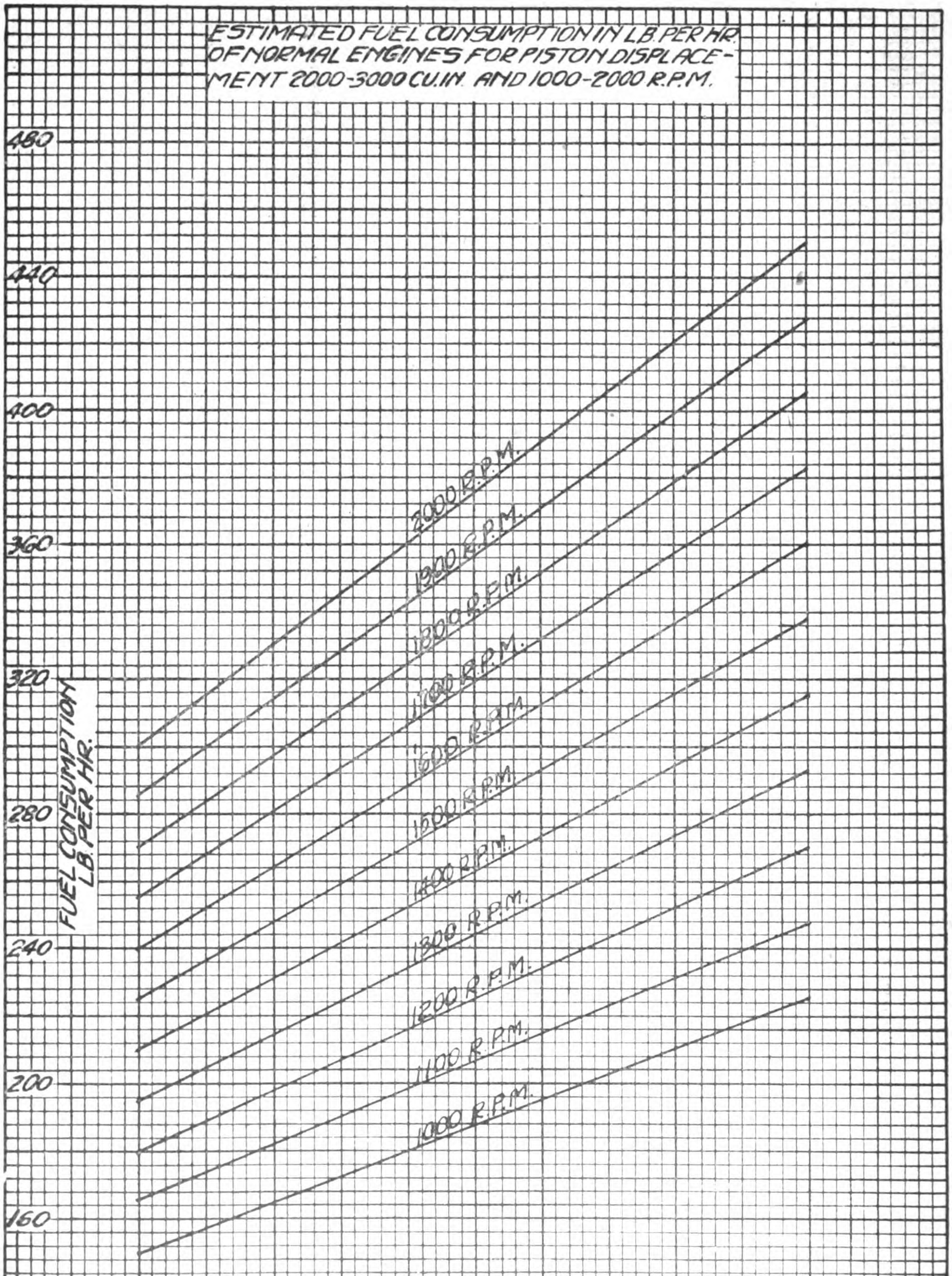

ESTIMATED FUEL CONSUMPTION IN LB. PER HR. OF NORMAL ENGINES FOR PISTON DISPLACEMENT 2000-3000 CU. IN. AND 1000-2000 R.P.M.
FUEL CONSUMPTION LB. PER HR.
480
440
400
360
320
280
240
200
160
2000 R.P.M.
1900 R.P.M.
1800 R.P.M.
1700 R.P.M.
1600 R.P.M.
1500 R.P.M.
1400 R.P.M.
1300 R.P.M.
1200 R.P.M.
1100 R.P.M.
1000 R.P.M.
PISTON DISPLACEMENT—CU. IN.
2000
2200
2400
2600
2800
3000

FIG. 7.

File D 10.16/7

McCOOK FIELD REPORT, SERIAL No. 1938

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | October 15, 1922 | No. 376

METHODS OF MAKING ALUMINUM BRONZE CASTINGS

(MATERIAL SECTION REPORT No. 174)

▽

Prepared by E. H. Dix, Jr., and Lieut. A. J. Lyon, A. S.
Engineering Division, Air Service,
McCook Field, Dayton, Ohio,
June 8, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

METHODS OF MAKING ALUMINUM BRONZE CASTINGS.

PURPOSE.

This investigation was undertaken in response to requests for aluminum bronze castings with the following objects in view:

1. To determine the mechanical properties and casting qualities of several compositions of aluminum bronze with varying iron and aluminum content.
2. To obtain experience in the foundry so as to be prepared to make castings of these alloys.

CONCLUSIONS.

1. The best mechanical properties were obtained in an alloy containing 7.98 per cent aluminum, 3.22 per cent iron, balance copper. This alloy in the "As cast" condition showed the following average properties:

Yield point, pounds per square inch	28,000
Ultimate strength, pounds per square inch	79,000
Elongation, per cent	45
Charpy impact, foot-pounds	35
Brinell hardness, 500 kg	130
Scleroscope	30
Rockwell No	73
Specific gravity	7.64
Modulus of elasticity	17,500,000

2. It was found that these alloys with proper precautions in regard to melting practice, and the same general methods of gating employed for manganese bronze, can be successfully cast. A maximum furnace temperature of 2,200° F. with a pouring temperature of 2,000° F. for average castings is recommended. Considerable care should be exercised to prevent oxidation by keeping the melt covered with a liberal covering of charcoal at all times. Large gates and ample risers are necessary, and bottom pouring through a skim gate which allows the metal to enter the mold with the least agitation possible is desirable.
3. These alloys are difficult to machine due to their great hardness and toughness, but are to be recommended in spite of this drawback where high strength and resistance to shock are required in a casting.

MATERIAL.

RAW MATERIALS.

The copper used for this investigation was foundry melt No. 856, of which five different ingots, weighing from 20 to 25 pounds each, were analyzed with the following results in per cent purity: 99.81, 99.81, 99.89, 99.83, 99.78. This is slightly under the Air Service specification, which requires a purity of 99.88 per cent.

The aluminum ingot used (melt No. 1045) was purchased from the British Aluminum Co. The analysis obtained by the Chemistry branch was as follows:

Copper	0.07
Silicon	.37
Iron	.47

The iron used was a light gauge tinned sheet obtained from stock.

The aluminum bronze ingot purchased from the Lumen Bearing Co. (melt No. 692) and used for comparative purposes was found on analysis to contain:

Copper	89.60
Aluminum	8.49
Iron	1.27
Zinc	.53
Silicon	.09
Tin	Nil.
Lead	Nil.

PROCEDURE.

PREPARATION OF HARDENERS.

The iron was introduced in the form of a copper-aluminum-iron hardener which was prepared by heating the iron and copper together in the Iler furnace and the aluminum in the Monarch furnace. When the copper was melted and brought to a good heat, the molten aluminum was poured into it with frequent stirring. The heat thus generated was sufficient to melt the iron and insure thorough solution. The hardener, melt No. 472, which was already on hand, had the following composition:

	As mixed.	Analysis.
Aluminum	67	65.18
Iron	11	13.85
Copper	22	20.97

The hardener, melt No. 1191, was made especially for this investigation with the following composition:

	As mixed.	Analysis.
Copper	60	58.86
Iron	20	20.90
Aluminum	20	20.24

Lumen Bearing Co. ingot:

Melt No.	722	1175
Total weight, pounds	120	80
Time in furnace, minutes	180	65
Maximum furnace temperature, °F	2,000	2,030
Pouring temperature, °F	1,950	1,980

Melted under a thick covering of charcoal.

The purpose of melt No. 722 was to obtain comparative test results from four different methods of casting test bars, sketches of which are included. Two molds (six bars) were cast according to pattern TB-1 (fig. 18). They were tested "as cast" without any machining. Two molds (six bars) TB-1A were cast in the same manner as TB-1 except that they were one-eighth inch larger in diameter, to allow for machining. They were tested in wedge grips after machining. Three molds of pattern TB-2A and TB-2B (figs. 19 and 20) were cast with wedge risers (three bars each). These patterns are similar except in the width of web joining the specimen and riser. TB-2A has a one-eighth-inch web and TB-2B a one-fourth-inch web. These bars were machined to size and tested in self-aligning adapters. One mold (one bar) of pattern TB-2S (fig. 21) was cast with a 7-inch riser. This bar was also machined to size and tested in self-aligning adapters.

EXPERIMENTAL MELTS.

Melt No.	1177	1180	1192	1195	1213
Aluminum	8	8	8	8	10
Iron	0	1.7	3	4	3
Copper	Bal.	Bal.	Bal.	Bal.	Bal.
Total weight, pounds	143.5	170	198	195.5	202.9
Time in furnace, minutes	165	210	180	220	215
Maximum furnace temperature, °F	2,150	2,070	2,220	2,200	2,160
Pouring temperature, °F	2,040	2,000	2,040	1,970	1,980
Hardener, melt No.	None.	472	1,191	1,191	1,191

In mixing these melts the copper was first melted down and brought to a good heat and then the iron hardener and additional aluminum held under the surface until thoroughly melted. Care was taken to prevent oxidation by a thick covering of charcoal and the metal was thoroughly stirred to insure complete mixing.

In all of these melts the following test bars were cast: Three 0.505 inch diameter tension specimens, pattern TB-2B. One modulus of elasticity tension specimen, pattern TB-8. Three porosity cups, pattern PC-2. One bar, 2¼ inches diameter by 12 inches long, to compare size of pipe formed. Several sample castings from patterns in foundry, in order to compare casting qualities of the different alloys.

METHODS OF TESTING.

The physical tests were performed according to standard procedure and require little comment except in respect to the modulus of elasticity tests and the impact tests. The modulus of elasticity tests were made on specimens three-fourths inch in diameter, with 8-inch gauge length. The deformation readings were taken on a Ewing extensometer. The Charpy impact tests were made in a standard American made Charpy impact machine on a 10 by 10 millimeter square specimen with the notch 2 millimeters in diameter and 5 millimeters deep.

RESULTS.

The results of the physical tests of these alloys are summarized in five tables and two curve sheets. The chemical analyses are given in Table 6. The report is illustrated by 1 photograph and 13 microphotographs.

DISCUSSION OF RESULTS.

METHOD OF CASTING TEST BARS.

The results of these tests as given in Table 1 indicate that the highest tensile strength and elongation are obtained from method of pattern TB-1. The high strength according to this method is accounted for by the strength of the skin which was not removed. A comparison of these results with the results of pattern TB-1A, which is similar in every respect except the bars are one-eighth inch larger in diameter, showed that about 5,000 to 6,000 pounds per square inch may be attributed to the "skin effect." Of the "machined" specimens, pattern TB-2B seems to give the highest, and at the same time, most consistent results. It is evident that the feeding action of the risers along the full length of the bar is counterbalanced by the slow rate of cooling due to the greater mass so that the effect of feeding in this manner is not nearly as pronounced as it is in the case of manganese-bronze test bars. For instance, pattern TB-2S which gives the highest results in manganese bronze, gave the lowest results in aluminum bronze. The microphotographs in Figures 9 to 14, inclusive, illustrate the effect of slow cooling, due to the greater mass in these test bars and explain the cause of the low tensile strength obtained on specimen TB-2S. Although these tests are not conclusive, it seems desirable to use pattern TB-2B for this alloy because of its very high shrinkage.

THE EFFECT OF IRON ON THE ALLOY CONTAINING 8 PER CENT ALUMINUM.

The effect of iron is shown graphically on curve sheets 1 and 2 (figs. 16 and 17). Referring first to curve sheet 1, it will be noted that iron very markedly raises the tensile strength and hardness and decreases the elongation. The Charpy impact value is lowered 50 per cent by the addition of 1.7 per cent iron, but this is probably accounted for by the fact that the specimens containing no iron were so very ductile that they were merely bent in the test and the friction of dragging the bars past the vise gave a fictitiously high value. The alloy without iron was so soft that two of the TB-2B specimens were spoiled in machining. The Charpy impact value of 35-foot pounds, obtained with 3 per cent iron, is very good. The effect of iron on the modulus of elasticity and proportional limit is well illustrated in curve sheet 2. Three per cent iron more than doubles the proportional limit and raises the modulus appreciably.

With this alloy, the addition of 3 per cent iron seems to be highly beneficial in regard to the mechanical properties.

COMPARISON OF THE 8 AND 10 PER CENT ALUMINUM ALLOYS.

A comparison of melts 1213 and 1192 shows that with 9.70 per cent aluminum and 3.20 per cent iron the tensile strength and elongation are both less than with the alloy

of 7.98 per cent aluminum and 3.22 per cent iron. It is therefore concluded that in an aluminum bronze containing substantial percentages of iron the aluminum content should not be much over 8 per cent. The best mechanical properties of the series were obtained with the above alloy of 7.98 per cent aluminum and 3.22 per cent iron. The appearance of the tension specimens after fracture is shown in Figure 1.

POROSITY TESTS.

The porosity test results are given in Table 5. The method employed in these tests is explained in detail in Material Section Report No. 160, Serial No. 1882. It will be noted that in general the series of alloys showed up very well in this test and that where leaks occurred they were due to casting defects rather than an inherent quality in the metal. However, it is a matter of practical experience that aluminum-bronze castings are very difficult to make tight against hydraulic or air pressure.

CASTING QUALITIES.

As previously stated, castings were made from several patterns on hand in the foundry in each of the experimental melts cast in order to investigate the casting qualities of these alloys, and in addition a bar 2¼ inches in diameter by 12 inches long was cast horizontally with a 2-inch diameter pouring head at one end and a 2-inch diameter riser at the other end, both being joined to the bar by heavy gates. Both the riser and pouring head showed good shrinkage in the top and the bar appeared sound in other respects. These bars were then sawed into 1-inch thick sections and they were found to contain pipes extending from the gates at the pouring end of the bar and in one instance from the riser end. The extent of this pipe is given in the following tabulation:

Melt No.	Length of pipe from pouring head.	Length of pipe from riser.
	Inches.	*Inches.*
1177	4¾	4
1180	7¾	0
1192	8¾	0
1195	9	0
1213	8½	0

This tabulation gives an indication of the high shrinkage of all of these alloys. It has been stated by H. Rix and H. Whitaker (see reference) that iron forms a refractory skeleton which reduces shrinkage and produces a fine grain. Although our tests indicated that iron has a tendency to form a fine-grain structure, there was no indication that it reduced the shrinkage of the alloys. It was, however, found that by methods of gating similar to those employed in the production of manganese bronze castings it was possible to very successfully cast the aluminum bronzes, and the castings had a beautiful golden color and appeared sound if the shrinkage was properly taken care of. It is necessary in melting this metal to use the utmost precaution to prevent oxidation, as the oxidation of aluminum produces hard particles of alumina which seriously interfere with machining.

MACHINING PROPERTIES.

The combined toughness and hardness of aluminum bronze makes it very difficult to machine, and this one factor has been the chief cause for the rather limited use which has been made of it. The iron considerably increases the Brinell hardness of the alloys and probably makes them more difficult to machine. Considerable difficulty was experienced in the foundry in removing the gates and risers by means of the band saw, used for all other nonferrous alloys. A few heavy gates were sufficient to spoil a new saw blade.

HEAT TREATMENT.

That the aluminum bronzes are subject to heat treatment in much the same manner as steel is a matter of common knowledge, and although few experiments have been made in this laboratory in regard to the heat treatment, it seems advisable to mention the hardness obtained in the several heat treatments which have been carried out. A section of an extruded bar (90 per cent copper, 10 per cent aluminum) 1¼ inches in diameter by 2½ inches long was subjected to several heat treatments with the results given below:

Time at temperature.	Temperature (° F.) (water quenched).	Brinell hardness (3,000 kg.).
As received		150
One-half hour	1,517	163
One-half hour	1,716	153
1 hour	1,780	154

A disk 3½ inches in diameter by 1 inch thick of melt 1213 (copper 87.10 per cent, iron 3.20 per cent, aluminum 9.7 per cent) was quenched in water after one-half hour at 1,472° F. with the following results:

	Brinell.		Scleroscope.
	500 kg.	3,000 kg.	
Before	122	129	20
After	143	165	32

METALLOGRAPHY.

The constitution of this series is indicated in the equilibrium diagram given in Figure 2, which represents the results of the most recent investigation. It will be noted that up to about 9 per cent aluminum the alloys consist of the single alpha solid solution. Beyond this percentage a second solid solution (beta) appears at high temperatures and breaks down into a eutectoid of alpha plus delta. Little information is available in regard to the constitution of the aluminum-iron-copper alloys, but it is known that the solubility of the iron is probably very low, and when present in excess it occurs in small particles, having a blue tinge and distinctly visible in the unetched specimen, thus indicating their relative hardness. As a result of the experience gained in connection with iron in manganese bronze, it is believed that this

iron constituent consists of an iron-rich solid solution of iron and copper.

Figures 3 and 4 illustrate the structure of the 7.80 per cent aluminum alloy containing 4.15 per cent iron. Figure 3 shows grain boundaries and well-distributed particles of iron constituent which appear white with black rings. There is a small amount of delta to be found at the grain boundaries, as may be faintly noted in Figure 4. Figures 5 and 6 illustrate the structure of the alloy containing 8.49 per cent aluminum and 1.28 per cent iron. In Figure 5 the large white areas are the alpha solid solution and the dark areas are the delta. In Figure 6, due to the different method of etching, the alpha appears mottled and the delta areas clear gray. The alpha in the eutectoid formation in the center of the particle of delta appears black, due to the deep etching. The iron constituent appears in small white globules. Figures 7, 8, and 9 illustrate the structure of an alloy of 9.70 per cent aluminum and 3.20 per cent iron. The average structure is shown in Figure 7 in which the white is alpha, the dark areas sprinkled with white are the alpha-delta eutectoid, and the black specks the iron constituent. Figure 8 shows the eutectoid at a higher magnification and also shows very faintly a white lacework structure in the center of the photograph. This structure was observed in the unetched specimen and appeared similar to the well-distributed particles of the iron constituent. Figure 9 illustrates this structure in a much clearer manner. The alpha areas are dark, the delta areas white, and the iron particles a slightly brighter white. The alpha particle in the center of the photograph is nearly completely surrounded by the envelope of a white lacelike constituent referred to above. All of these microphotographs were taken from the three-fourths inch diameter end of test bars cast according to pattern TB-2B. Figures 10 to 15 illustrate the effect of rate of cooling on the structure of the test bars of the alloy containing 8.49 per cent aluminum and 1.28 per cent iron. Attention is directed to the areas in the center of Figure 12 which appear darker than the eutectoid areas in the rest of the photograph. These areas are shown at higher magnification in Figure 13. They are of the same lacework structure referred to in connection with Figure 9, but due to the method of etching it is rather difficult to distinguish this from the alpha-delta eutectoid. The arrows in Figure 13 indicate the boundary between this constituent and the alpha-delta eutectoid. Figures 5 and 10 are of specimens cast from the same original ingot and are very similar; differences in tone are due to slight differences in time of etching and of exposure in photographing and printing.

LITERATURE REVIEW.

The following articles, which were all that were available in Dayton, were reviewed in connection with this investigation.

Eighth Report to the Alloys Research Committee of the Institute of Mech. Engr. British.

This is a very comprehensive study of the binary copper-aluminum alloys made by Prof. H. C. H. Carpenter and Mr. C. A. Edwards.

Institute of Metals, Vol. X, 1913, No. 2, page 344. The Influence of Phosphorus on Some Copper-Aluminum Alloys. By Prof. A. A. Read.

This is an investigation of the effects of phosphorus on the alloys of copper and aluminum containing 1, 5, and 10 per cent aluminum.

Institute of Metals, Vol. VIII, 1915, No. 1, page 249. Some Experiments on Copper-Aluminum Alloys. By J. H. Andrew.

This paper deals entirely with the constitution diagram and is the most valuable and thorough work on the metallography of this series. The equilibrium diagram given in this report was taken from this paper.

A. S. T. M., Vol. XVI, 1916, page 118. Aluminum Bronze: Some Recent Tests and their Significance. By W. M. Corse and G. F. Comstock.

A very good paper, covering endurance tests and heat treatment in detail. It points out the superiority of aluminum bronze over manganese bronze in point of view of endurance.

Institute of Metals, Vol. XIX, 1918, No. 1, page 55. The Constitution of the Copper-Rich Aluminum Copper Alloys. By J. Neill Greenwood.

This article is an attempt to classify the metallographic constituents of aluminum bronze by Brinell hardness tests.

Institute of Metals, Vol. XIX, 1918, No. 1, page 123. Die Casting of Aluminum Bronze. By H. Rix and H. Whitaker. Also an abstract in Chemical & Metallurgical Engineering, Vol. XX, No. 3, Feb. 1, 1919.

Composition 7 to 10 per cent alumium, 1 to 4 per cent iron. Some iron and aluminum enter into solid solution with copper, forming the alpha constituent, but the bulk properly separates out as a high melting point $FeAl_3$ which forms a skeleton in which the residual metal solidifies. This refractory skeleton thus reduces the shrinkage and produces a fine grain. The iron also increases the yield point and tensile strength at the expense of the ductility. The above alloys show no alpha constituent.

Iron should be added as pure wrought-iron chips; silicon is fatal. Melted at as low a temperature as possible; melting practice is responsible for many blow holes and other defects. Bottom gating gives a flow of metal which has a cleaning effect.

Best material for dies is chilled-cast close-grained gray iron as hard as can be machined. It gives the following analyses of dies which have given satisfactory service:

Phosphorus	1.30	0.89
Combined carbon	.14	.84
Graphitic carbon	3.35	2.76
Silicon	2.40	2.02
Manganese	.43	.29
Sulphur	.10	.07

Chem. & Met. Engr., Vol. XXI, No. 15, Dec. 24 and 31, 1919. Experience with a 91-9 Copper-Aluminum Alloy. By A. I. Krynitzky.

This composition was used for time fuses at a time-fuse plant in Petrograd, Russia. He states that purity

of raw materials is important and that high aluminum rods have a tendency to fracture through cold working. The skin should always be removed before rolling and drawing. He states that machining of these alloys is not difficult.

Chem. & Met. Engr., Aug. 15, 1919, page 179. Relation of Microstructure to Phase Change in Heat-Treated Aluminum Bronzes. By L. R. Seidell and G. J. Horvitz.

Transactions S. A. E., April, 1918. Aluminum Bronzes. By W. M. Corse. Also abstracted in Chem. & Met. Engr. Vol. XX, No. 4, Feb. 15, 1919.

He states that the use of aluminum in copper alloys was discovered in 1855 by Lord Percy. The usual composition is 90 per cent copper, 10 per cent aluminum. He gives the following comparison between aluminum bronze and phosphor bronze for worm gears:

I: Phorphor bronze. Copper 88 per cent, tin 11 per cent, phosphor 0.3 per cent.

II: Aluminum bronze, Aluminum 10 per cent, iron 1 per cent, copper 89 per cent.

	I.	II.
T. S., lbs. per sq. in	35,000–40,000	65,000–80,000
Y. P. elong. 6–10/20–30	22,000–25,000	23,000–28,000
Red. of area, %	7–9	21–29
Specific gravity	8.5	7.5
Brinell, 500 kg		92–100
Shrinkage per foot	0.125	0.22
Wt. per cu. in., lb	0.31	0.27
Comp. E. L	16,000	10,000
Coef. of friction	0.0040	0.0025
Res. to impact, Fremont, 7 x 10 mm	2–4	7–10
Endurance, Landgraf & Turner	150–400	3,500–5,500
Res. to shear impact, McAdam	300–450	750–850
Mod. of elasticity	12 x 10^6–14 x 10^6	15 x 10^6–18 x 10^6

Cast aluminum bronze possesses properties equal to the rolled or forged alloys.

Bronze Mangalum No. 100. Essai 4.511.

Copper, 90.10 per cent; aluminum, 9.55 per cent; manganese, 0.28 per cent; iron, 0.07 per cent; silicon, trace; lead, tin, nickel, zinc, nil. Heat treatment: Quench begins to be effective at 700° C. (1,292° F.); but is not complete until 800° C. (1,472° F.). 900° C. (1,652° F.) seems to be higher than necessary and gives a coarse grain. Drawing temperatures after 800° C. quench: 500° C. (932° F.) begins to be effective; 700° C. (1,292° F.) most desirable. Properties after quench from 800° C. (1,472° F.) and draw 600 to 700° C. (1,112–1,192° F.). Tensile strength, 78,000 lbs. per sq. in.; elongation, 20 per cent; Charpy 8 kg. m., 56.2 ft. lb. 10 x 10 mm. spec. 1 mm. rad. notch 2 mm. deep.

Metal Industry, Vol. XVIII, No. 11, 1920, page 520. Die Casting Aluminum Bronze. By the Buffalo Bronze Die Casting Co.

Data from letter of W. H. Bassett, American Brass Co., June 25, 1921.

	5% Al.	8% Al.
Specific gravity	8.176	7.80
Wt., per cu. in	0.2954 lb.	0.2818 lb.
Wt., per cu. ft	510.41 lb.	486.94 lb.

Physical properties, 8 per cent aluminum ½ in. diameter rods:

	Tensile strength.	Elongation.
Hard drawn	100,000	2
Annealed	60,000	50

10 per cent aluminum, 3 per cent iron, 87 per cent copper.

1$\frac{1}{16}$ in. rods extruded, annealed and drawn to size. Tensile strength, 105,200; elongation, 14 per cent; R. 24 per cent.

1$\frac{5}{16}$ in. rods. Tensile strength, 99,600; elongation, 23 per cent.

Coefficient of Expansion. Bureau of Standards Scientific Paper No. 40, page 159.

92.17 per cent copper, 7.34 per cent aluminum, 0.40 per cent zinc, 0.09 per cent silicon is—

0.0000166 from 25 to 100° C.

0.0000179 from 25 to 300° C.

TABLE 1.—*Effect of methods of casting test bars—Lumen Bearing Co.*

TB-1—"AS CAST."

Specimen marked	722-1A	722-1B	722-1C	722-4A	722-4B	722-4C	Ave.
Orig. dia., in	0.492	0.497	0.484	0.483	0.500	0.494	....
Yld. point, lb./sq. in	30,240	30,930	32,070	27,290	27,500	27,860	29,315
Ult. str., lb./sq. in	67,540	69,070	74,460	75,810	66,970	71,060	70,820
Elong. in 2 in., %	21.5	21.5	25.0	29.0	23.0	25.0	24.3
Location of fract	O. T.	O. T.	M. T.	O. T.	M. T.	O. T.	....
Character of fract	Diag.	Diag.	Diag.	Diag.	Diag.	Diag.	....
Brinell, 500 kg	100	93	93	93	93	96	94.67
Scleroscope	22	23	23	23	24	23	23

TB-1A—"MACHINED."

Specimen marked	722-2A	722-2B	722-2C	722-5A	722-5B	722-5C	Ave.
Orig. dia., in	0.500	0.500	0.501	0.498	0.498	0.502	....
Yld. point, lb./sq. in	36,410	35,650	42,100	38,660	39,530	39,410	38,625
Ult. str., lb./sq. in	67,840	53,620	65,030	67,250	69,560	66,690	64,995
Elong. in 2 in., %	22.0	12.5	20.5	22.0	23.5	26.0	21.1
Location of fract	M. T.	O. T.	M. T.	M. T.	M. T.	O. T.	....
Character of fract	Diag.	Diag.	Diag.	Jagged.	Jagged.	Jagged.	....
Brinell, 500 kg	80	83	93	86	93	89	87.3
Scleroscope	26	26	27	24	23	23	24.8
Specific gravity	7.68	7.58	7.54	7.71	7.54	7.50	7.59

Table 1.—*Effect of methods of casting test bars—Lumen Bearing Co.*—Continued.

TB-2A—½-IN. WEB.

Specimen marked	722-3A	722-6A	722-8A	Ave.
Orig. dia., in	0.498	0.501	0.498	....
Yld. point, lb./sq. in	31,190	32,360	34,400	32,650
Ult. str., lb./sq. in	57,120	63,410	63,760	61,430
Elong. in 2 in., %	16.5	23.0	21.5	20.3
Location of fract	O. T.	O. T.	M. T.	....
Character of fract	Rough.	Rough.	Rough.	....
Brinell, 500 kg	86	93	86	88.3
Scleroscope	26	25	23	24.6
Specific gravity	7.62	7.58	7.56	7.59

TB-2B—½-IN. WEB.

Specimen marked	722-3B	722-6B	722-8B	Ave.
Orig. dia., in	0.500	0.500	0.501	....
Yld. point, lb./sq. in	32,700	33,610	34,490	33,600
Ult. str., lb./sq. in	67,740	64,370	65,440	65,850
Elong. in 2 in., %	25	22.5	26	24.5
Location of fract	O. T.	M. T.	O. T.	....
Character of fract	Rough.	Rough.	Rough.	....
Brinell, 500 kg	96	93	93	94
Scleroscope	25	24	25	24.6
Specific gravity	7.73	7.54	7.67	7.65

TB-2S—7-IN. RISER.

Specimen marked	722-7
Orig. dia., in	0.498
Yld. point, lb./sq. in	30,800
Ult. str., lb./sq. in	57,910
Elong. in 2 in., %	24.5
Location of fract	O. T.
Character of fract	Rough.
Brinell, 500 kg	89
Scleroscope	23
Specific gravity	7.47

Table 2.—*Tests on TB-2B.*

Added aluminum Added iron	8.0 0.0	8.0 1.7		Ave.
Specimen marked	1177-4	1180-5	1180-6	....
Orig. dia., in	0.500	0.501	0.500	....
Yld. point, lb./sq. in	15,280	23,230	24,450	23,840
Ult. str., lb./sq. in	52,410	61,630	65,900	63,760
Elong. in 2 in., %	78.0	39	49	44
Location of fracture	M. T.	O. T.	M. T.	....
Character of fract	Drawn.	Withered.	Drawn.	....
Brinell, 500 kg	35	109	124	116-5
Scleroscope	12	22	28	25
Specific gravity	7.48	7.68	7.76	7.72
Rockwell No	37	72	68	70

Added aluminum Added iron	8.0 3.0			Ave.	8.0 4.0			Ave.
Specimen marked	1192-1	1192-4	1192-5	....	1195-4	1195-5	1195-6	....
Orig. dia., in	0.501	0.504	0.501	....	0.500	0.497	0.500	....
Yld. point, lb./sq. in	26,380	29,070	28,410	27,950	28,520	28,350	27,760	28,210
Ult. str., lb./sq. in	78,830	78,290	80,150	79,090	77,510	78,300	79,450	78,420
Elong. in 2 in., %	48.0	43.0	43.5	44.8	29	28.5	45.0	34.2
Location of fract	M. T.	M. T.	M. T.	....	M. T.	M. T.	M. T.	....
Character of fract	Jagged.	Jagged.	Jagged.	....	Jagged.	Jagged.	Jagged.	....
Brinell, 500 kg	....	136	124	130	130	....	119	124.5
Scleroscope	....	33	26	29.5	31	....	26	28.5
Specific gravity	....	7.75	7.64	7.70	7.73	....	7.73	7.73
Rockwell No	....	70	76	73	70	....	72	71

TABLE 2.—*Tests on TB-2B*—Continued.

LUMEN BEARING CO.

Added aluminum Added iron			Ave.		10 3		Ave.
Specimen marked	1175-4	1175-5	....	1213-4	1213-5	1213-6	....
Orig. dia., in	0.500	0.497	....	0.501	0.500	0.500	....
Yld. point, lb./sq. in	32,090	26,500	29,290	28,910	31,070	34,630	31,540
Ult. str. lb./sq. in	59,380	64,330	61,850	71,370	80,110	75,740	75,740
Elong. in 2 in., %	24	33.5	28.75	16	21.5	25.5	21.0
Location of fract	O. T.	M. T.	....	M. T.	O. T.	O. T.	....
Character of fract	Jagged.	Drawn.	....	Sml. flaw.	Jagged.	Jagged.	....
Brinell, 500 kg	93	109	101	....	105	130	117.5
Scleroscope	27	29	28	....	25	38	31.5
Specific gravity	....	....	....	....	7.32	7.49	7.41
Rockwell No	46	66	56	....	71	71	71

TABLE 3.—*Modulus of elasticity tests.*

Specimen marked	1177-7	1180-8	1192-8	1195-8	1213-8
Diameter, in	0.745	0.747	0.747	0.751	0.749
Proportional limit, lb./sq. in	7,000	14,000	18,500	16,000	11,500
Ult. str., lb./sq. in	41,870	60,280	73,950	66,170	58,960
Elong., % in 2 in	50.0	36.5	30.5	18.5	10.0
Elong., % in 4 in	49.5	33.75	28.0	17.5	9.5
Elong., % in 8 in	49.4	32.75	26,625	15,875	8.375
Reduction of area, %	53.7	34.6	32.0	28.7	16.8
Location of fract	O. S. G.	M. T.	O. T.	M. T.	M. T.
Character of fract (small flaws in every break)	Drawn.	Square.	Jagged.	Square.	Square.
Modulus of elasticity	15,380,000	15,450,000	17,550,000	16,950,000	16,530,000

TABLE 4.—*Charpy impact tests.*

Specimen marked No.	Impact ft. lb.	Brinell, 500 kg.	Specimen marked No.	Impact ft. lb.	Brinell, 500 kg.	Specimen marked No.	Impact ft. lb.	Brinell, 500 kg.	Specimen marked No.	Impact ft. lb.	Brinell, 500 kg.	Specimen marked No.	Impact ft. lb.	Brinell, 500 kg.
1177-1-8	76.09	45	1180-1-7	33.63	74	1192-1-7	33.63	89	1195-1-7	30.60	93	1213-1-7	13.24	100
1177-2-8	64.66	48	1180-2-7	36.74	80	1192-2-7	32.11	93	1195-2-7	30.60	96	1213-2-7	13.24	100
1177-3-8	72.26	48	1180-3-7	35.22	77	1192-3-7	32.11	86	1195-3-7	30.60	93	1213-3-7	14.39	100
1177-4-8	72.26	48	1180-4-7	40.00	80	1192-4-7	35.22	93	1195-4-7	33.63	93	1213-4-7	15.76	100
1177-5-8	70.38	45	1180-5-7	30.60	80	1192-5-7	36.74	93	1195-5-7	30.60	93	1213-5-7	14.39	100
1177-6-8	68.42	48	1180-6-7	33.63	80	1192-6-7	38.41	93	1195-6-7	30.60	93	1213-6-7	14.39	100
1177-7-8	72.26	45	1180-7-7	33.63	77	1192-7-7	38.41	89	1195-7-7	30.60	93	1213-7-7	14.39	100
1177-8-8	74.21	48	1180-8-7	36.74	74	1192-8-7	36.74	93	1195-8-7	30.60	93	1213-8-7	15.76	100
Av.	71.32	46.87	Av.	35.02	77.75	Av.	35.42	91.12	Av.	30.98	93.375	Av.	14.44	100

TABLE 5.—*Porosity tests.*

Cup No.	Number seconds for 1,000 c.c. to leak through. Pressure 115 pounds.	Cup No.	Number seconds for 1,000 c.c. to leak through. Pressure 115 pounds.	Cup No.	Number seconds for 1,000 c.c. to leak through. Pressure 115 pounds.
1177-1	8	1180-3	No leak.	1195-3	115
1177-2	No leak.	1192-1	48	1213-1A	35
1177-3	No leak.	1192-2	No leak.	1213-2A	15
1180-1	280	1192-3	95	1213-3A	300
1180-2	80	1195-1	No leak.		

Those cups that leaked did so in spots only, due probably to cold shuts or sand holes. The metals were good, but local flaws caused leakage.

TABLE 6.—*Chemical analysis.*

Melt No.	Copper.	Iron.	Aluminum (by dif.).	Zinc.	Silicon.	Tin.	Lead.
722 1175	89.60	1.28	8.49	0.53	0.10	Nil.	Nil.
1177	91.98	.18	7.84	....	....	....	....
1180	90.31	1.76	7.93	....	....	....	....
1192	88.80	3.22	7.98	....	....	....	....
1195	88.05	4.15	7.80	....	....	....	....
1213	87.10	3.20	9.70	....	....	....	....

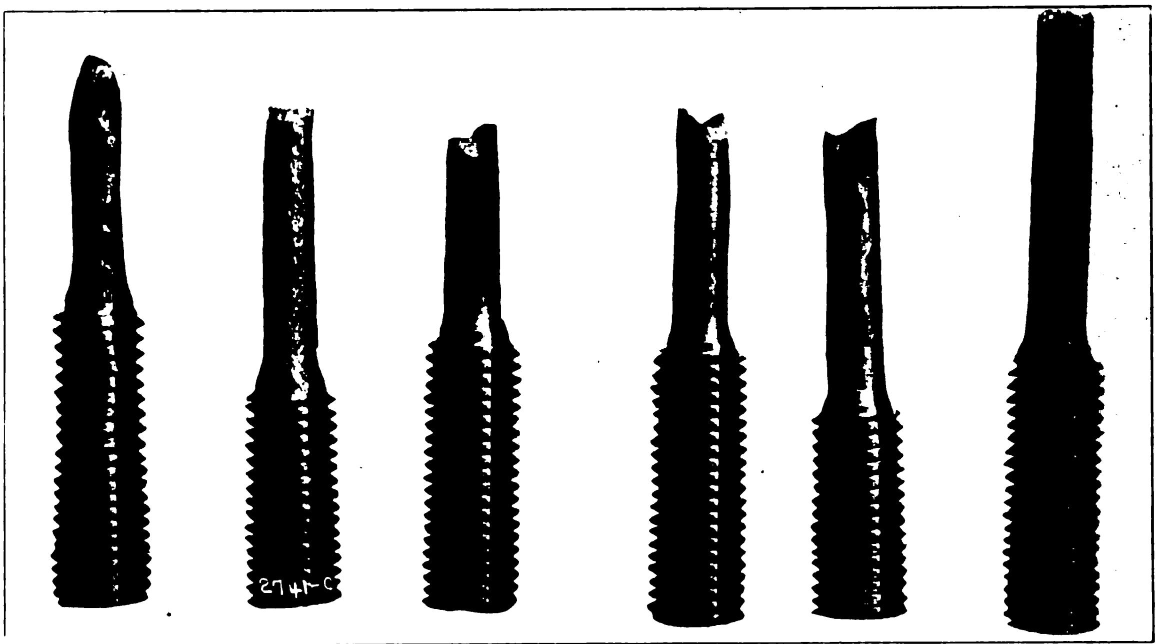


FIG. 681-1.—Fractured test bars.

	1177.	1180.	1192.	1195.	1175. Approximate.	1213.
Al	7.86	7.93	7.98	7.80	10	9.70
Fe	0.18	1.76	3.22	4.15		3.20
Cu	91.96	90.31	88.80	88.05	90	87.10
T. S.	[1] 52,400	[1] 63,800	[1] 79,000	[1] 78,420	[1] 61,850	[1] 75,740
E	[2] 78	[2] 44	[2] 45	[2] 34	[2] 29	[2] 22
Br	35	116	130	125	101	118

[1] Pounds per square inch.

[2] Percent.

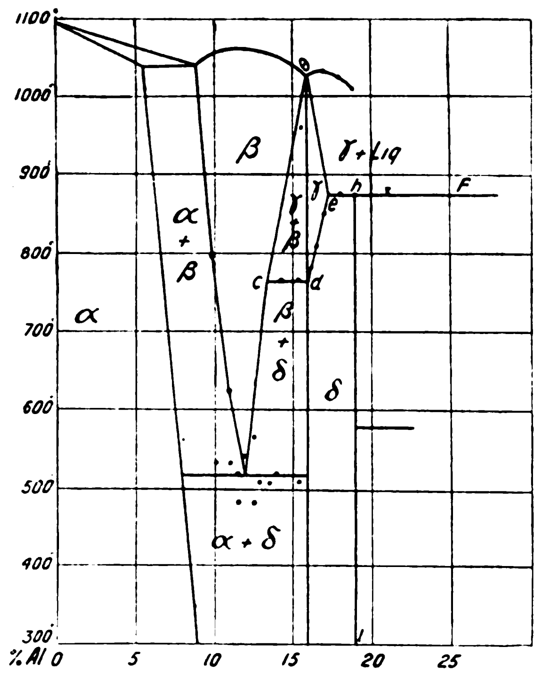


FIG. 681-2.—Constitutional diagram according to Andrew.

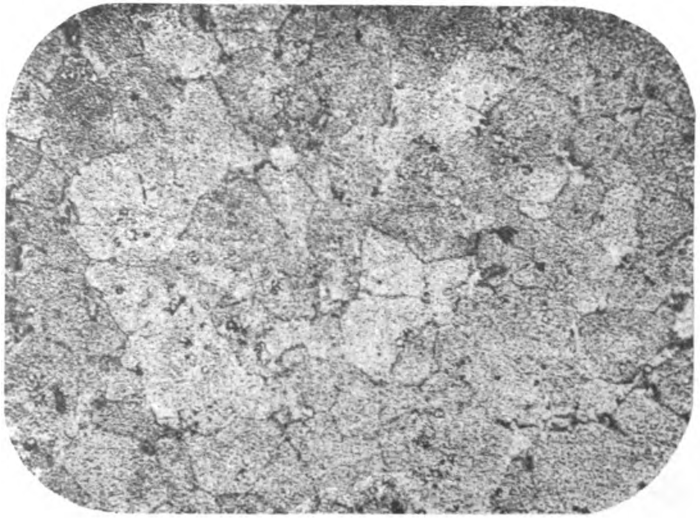


Fig. 681-3.—Magnification 100 diameters. Specimen 1195—Composition: Al 7.80, Fe 4.15, Cu 88.05. Etching: Copper ammonium chloride followed by concentrated HNO_3. Remarks: Note grain boundaries and light particles of iron constituent.

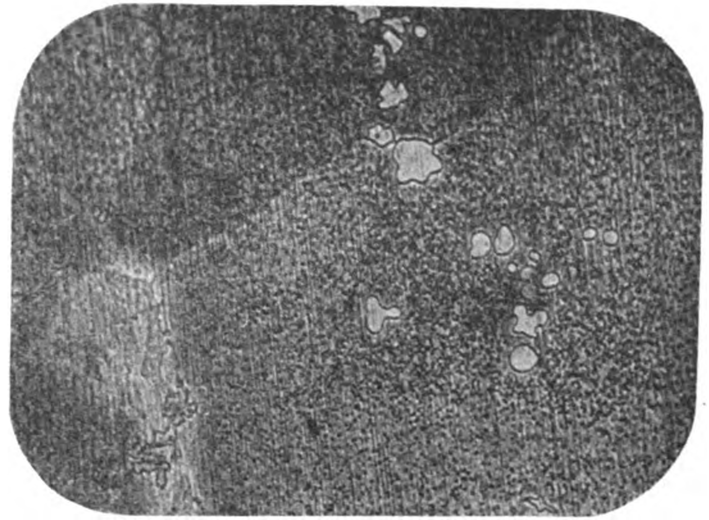


Fig. 681-4.—Magnification 500 diameters. Specimen 1195—Composition: Al 7.80, Fe 4.15, Cu 88.05. Etching: $NH_4OH + H_2O_2$. Remarks: Note trace of delta in grain boundary and light particles of iron constituent.

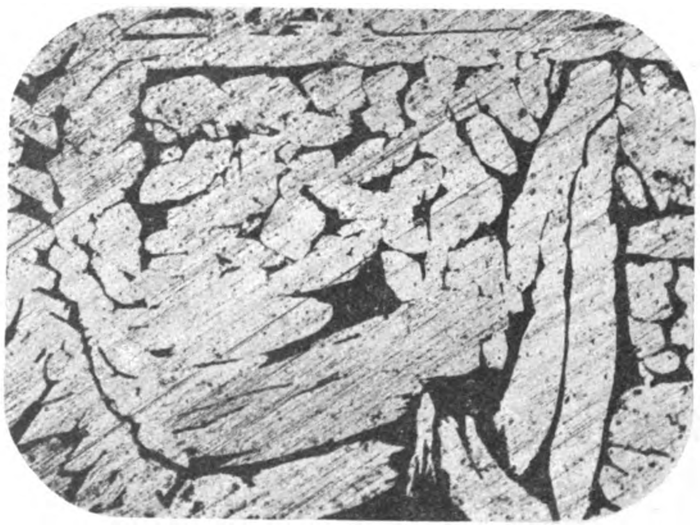


Fig. 681-5.—Magnification 100 diameters. Specimen 1175—Composition: Al 8.49, Fe 1.28, Cu 89.60. Etching: $FeCl_3$. No. 5 of B. S. S c.399. Remarks: Average structure.

Fig. 681-6.—Magnification 500 diameters. Specimen 1175—Composition: Al 8.49, Fe 1.28, Cu 89.60. Etching: Copper ammonium chloride followed by concentrated HNO_3. Remarks: Alpha and alpha delta eutectoid with small light particles of iron constituent.

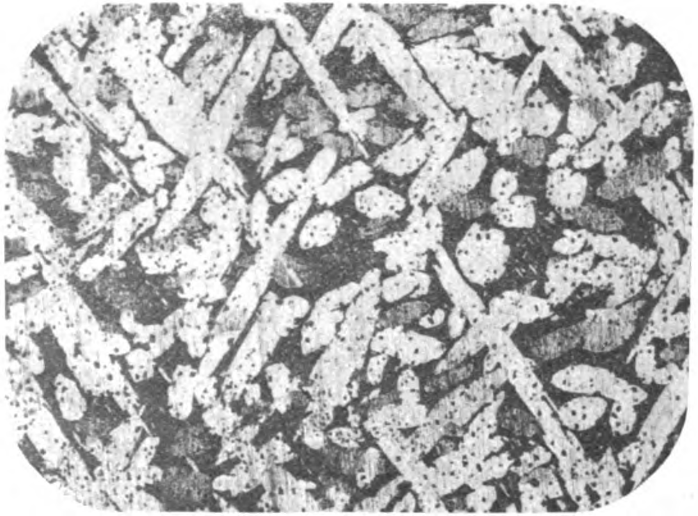


Fig. 681-7. Magnification 100 diameters. Specimen 1213—Composition: Al 9.70, Fe 3.20, Cu 87.10. Etching: $FeCl_3$. Remarks: Black specks are iron constituent.

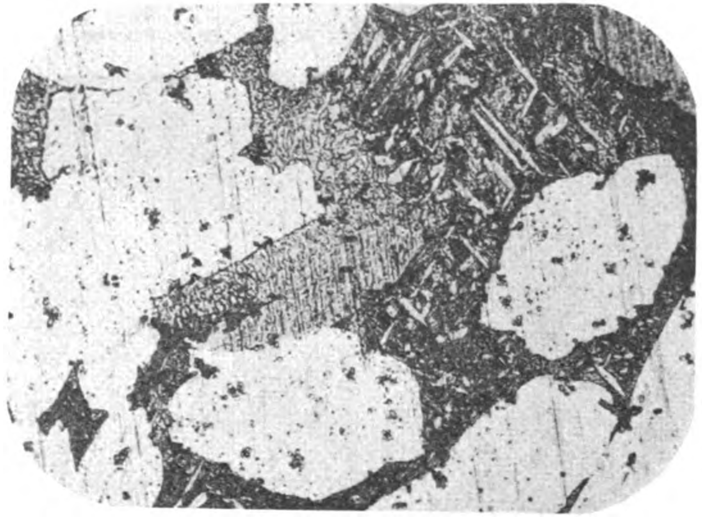


Fig. 681-8.—Magnification 500 diameters. Specimen 1213—Composition: Al 9.70, Fe 3.20, Cu 87.10. Etching: $FeCl_3$. Remarks: Note alpha delta eutectoid.

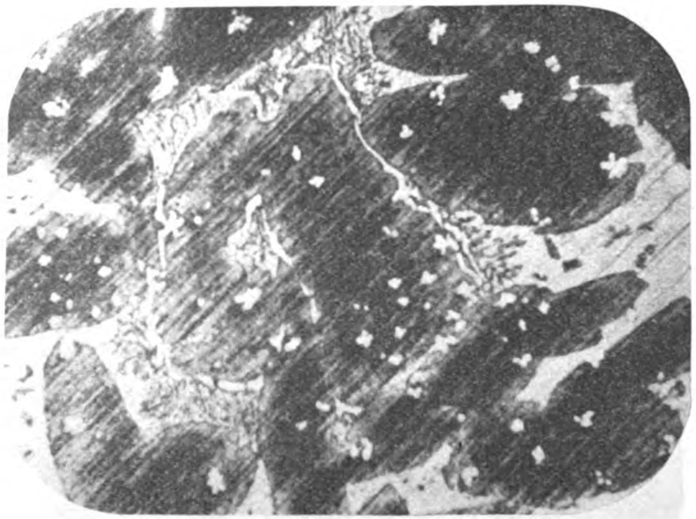


Fig. 681-9.—Magnification 500 diameters. Specimen 1213—Composition: Al 9.70, Fe 3.20, Cu 87.10. Etching: Copper ammonium chloride followed by concentrated HNO_3. Remarks: Large white areas are delta; small white particles iron constituent, and white lace work having same metallographic characteristics as the iron particles.

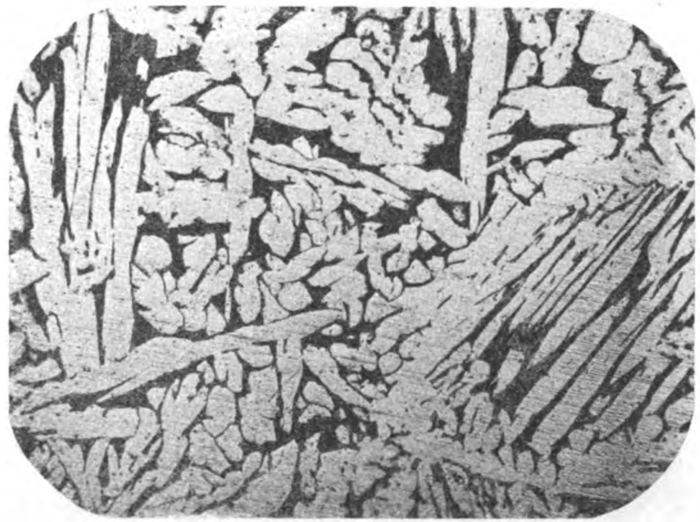


Fig. 681-10.—Magnification 100 diameters. Specimen 722-2 C. Etching: $FeCl_3$. Remarks: Structure of test bar cast according to pattern TB 1.

FIG. 681-11.—Magnification 500 diameters. Specimen 722-2-C. Etching: $FeCl_3$.
Remarks: Structure of test bar cast according to pattern TB-1.

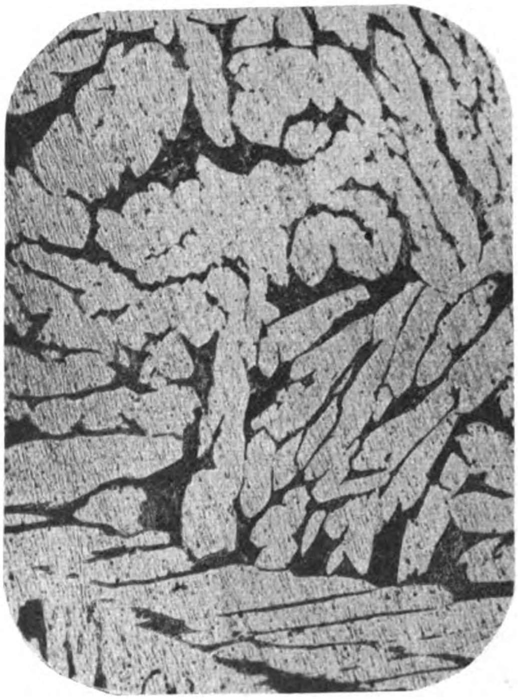


FIG. 681-12.—Magnification 100 diameters. Specimen 722-B-6. Etching: $FeCl_3$.
Remarks: Structure of test bar cast according to pattern TB-2B.

FIG. 681-13.—Magnification 500 diameters. Specimen 722-B-6. Etching: $FeCl_3$.
Remarks: Structure of test bar cast according to pattern TB-2B.

FIG. 681-14.—Magnification 100 diameters. Specimen 722-7. Etching $FeCl_3$.
Remarks: Structure of test bar cast according to pattern TB-2B.

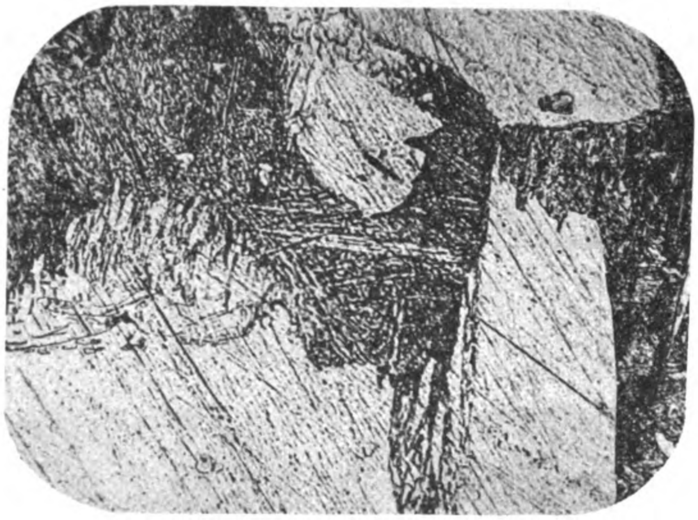


FIG. 681-15.—Magnification 500 diameters. Specimen 722-7. Etching $FeCl_3$.
Remarks: Structure of test bar cast according to pattern TB-2S.

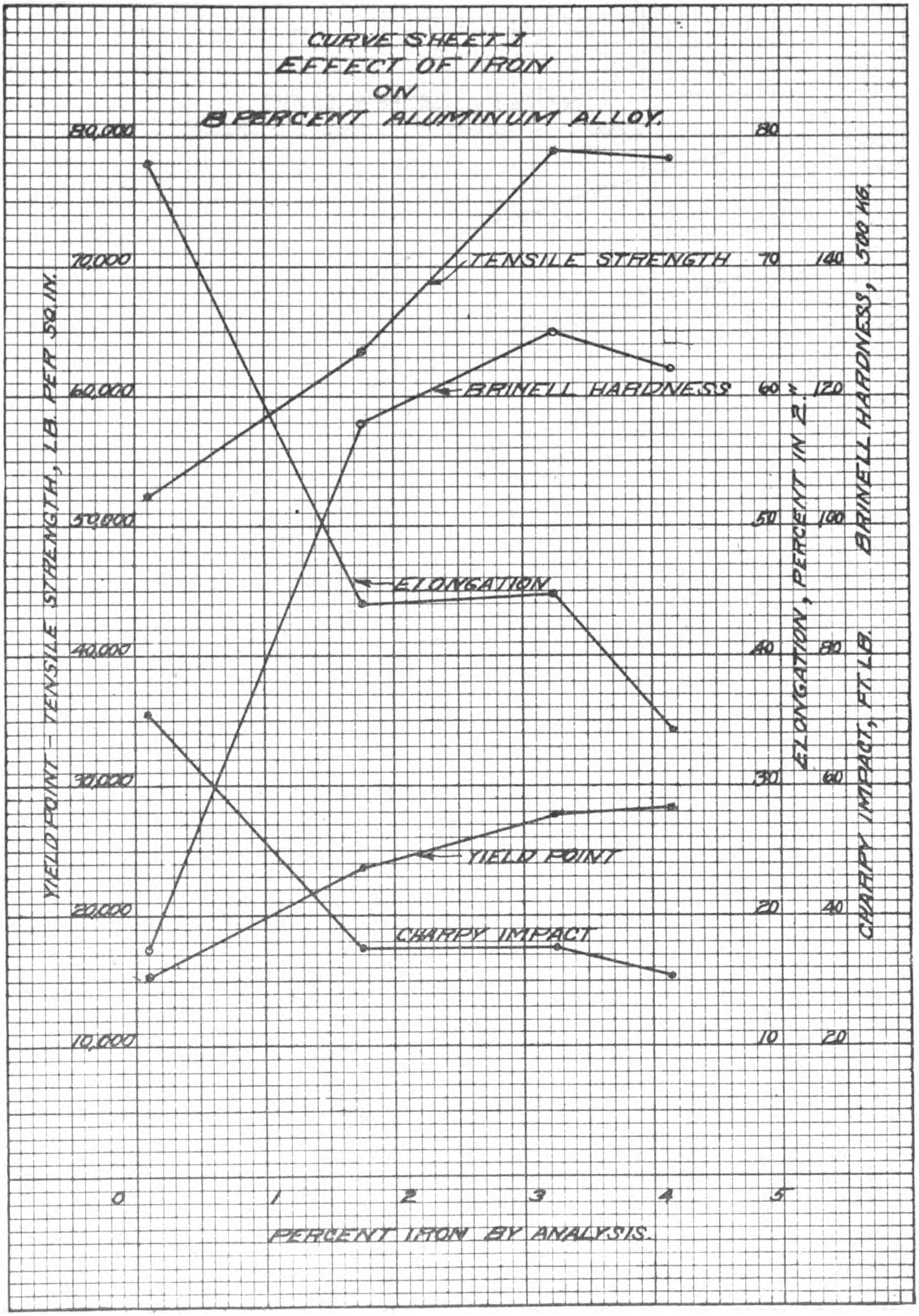

CURVE SHEET I
EFFECT OF IRON
ON
8 PERCENT ALUMINUM ALLOY.
TENSILE STRENGTH
BRINELL HARDNESS
ELONGATION
YIELD POINT
CHARPY IMPACT
YIELD POINT - TENSILE STRENGTH, LB. PER SQ. IN.
ELONGATION, PERCENT IN 2"
BRINELL HARDNESS, 500 KG.
CHARPY IMPACT, FT. LB.
PERCENT IRON BY ANALYSIS.
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
80
70
60
50
40
30
20
10
140
120
100
80
60
40
20
0
1
2
3
4
5

FIG. 16.

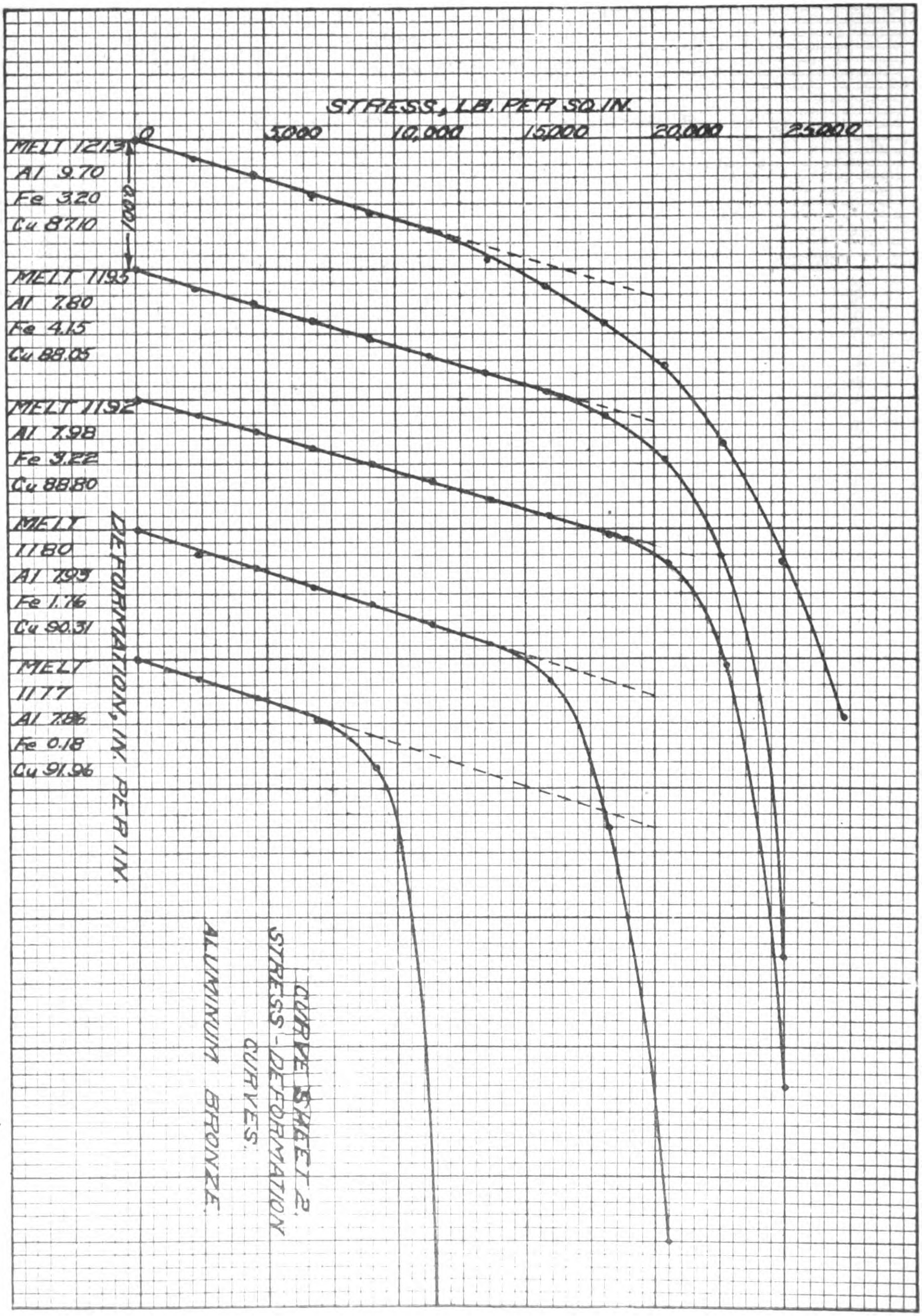

STRESS, LB. PER SQ. IN.
0
5000
10,000
15,000
20,000
25000
MELT 1213
Al 9.70
Fe 3.20
Cu 87.10
.001
MELT 1193
Al 7.80
Fe 4.15
Cu 88.05
MELT 1192
Al 7.98
Fe 3.22
Cu 88.80
MELT 1180
Al 7.93
Fe 1.76
Cu 90.31
MELT 1177
Al 7.86
Fe 0.18
Cu 91.96
DEFORMATION, IN. PER IN.
CURVE SHEET 2.
STRESS-DEFORMATION CURVES.
ALUMINUM BRONZE

FIG. 17.

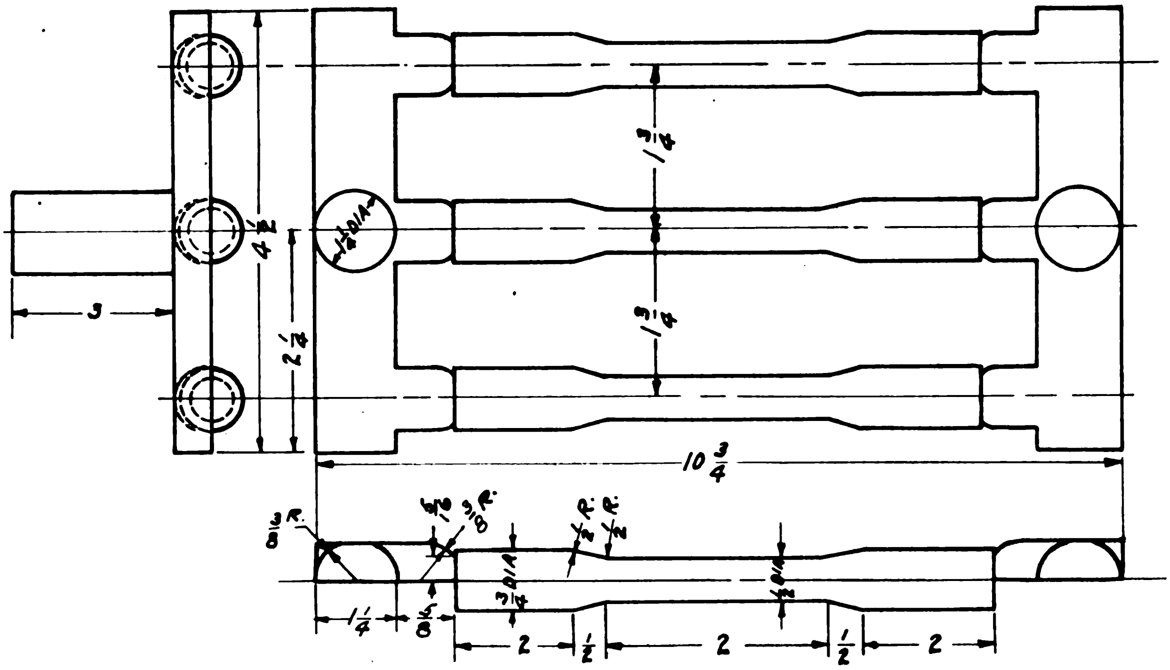


FIG. 18.—Pattern No. TB—1.

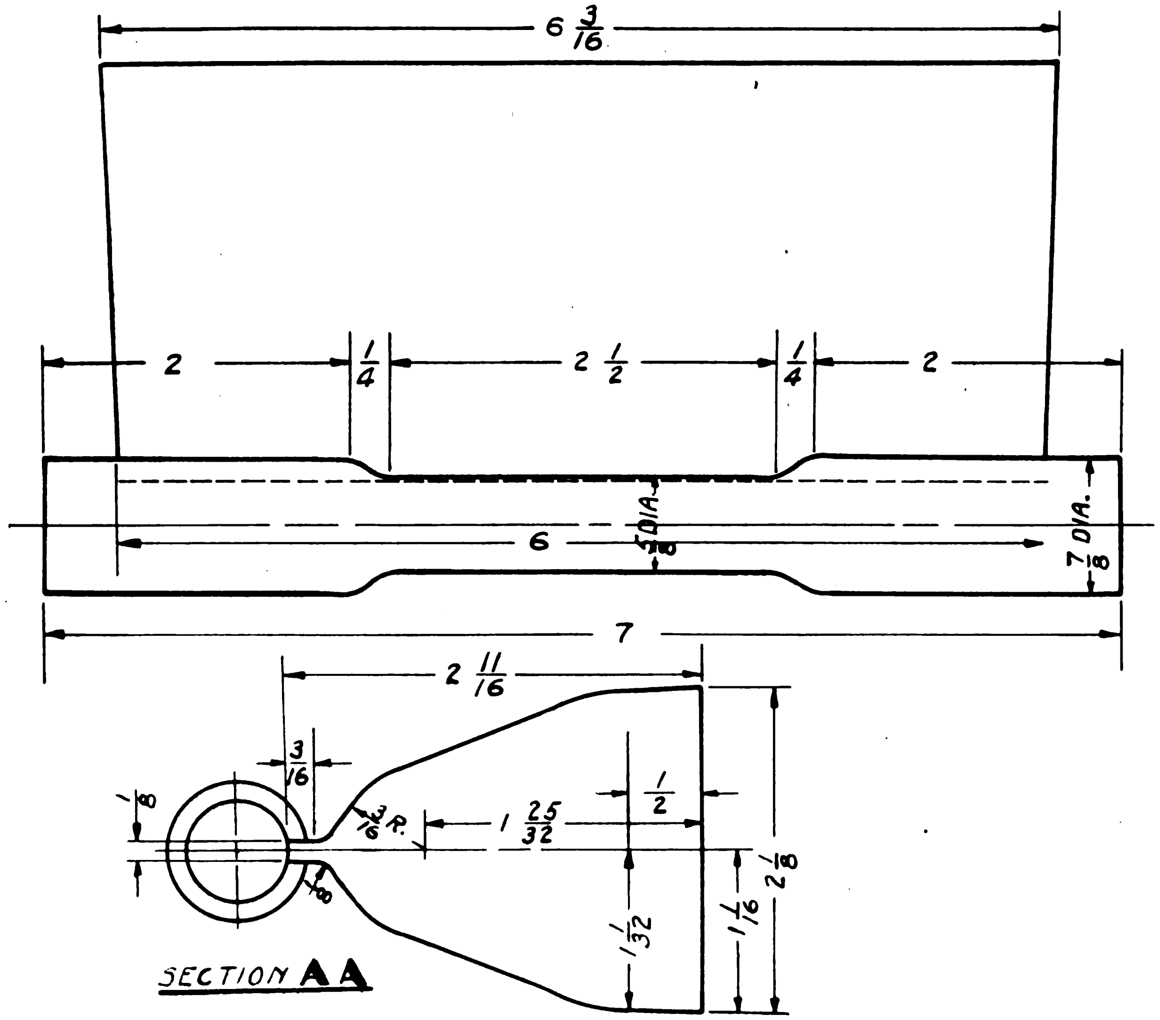


FIG. 19.—Pattern No. TB-2A.

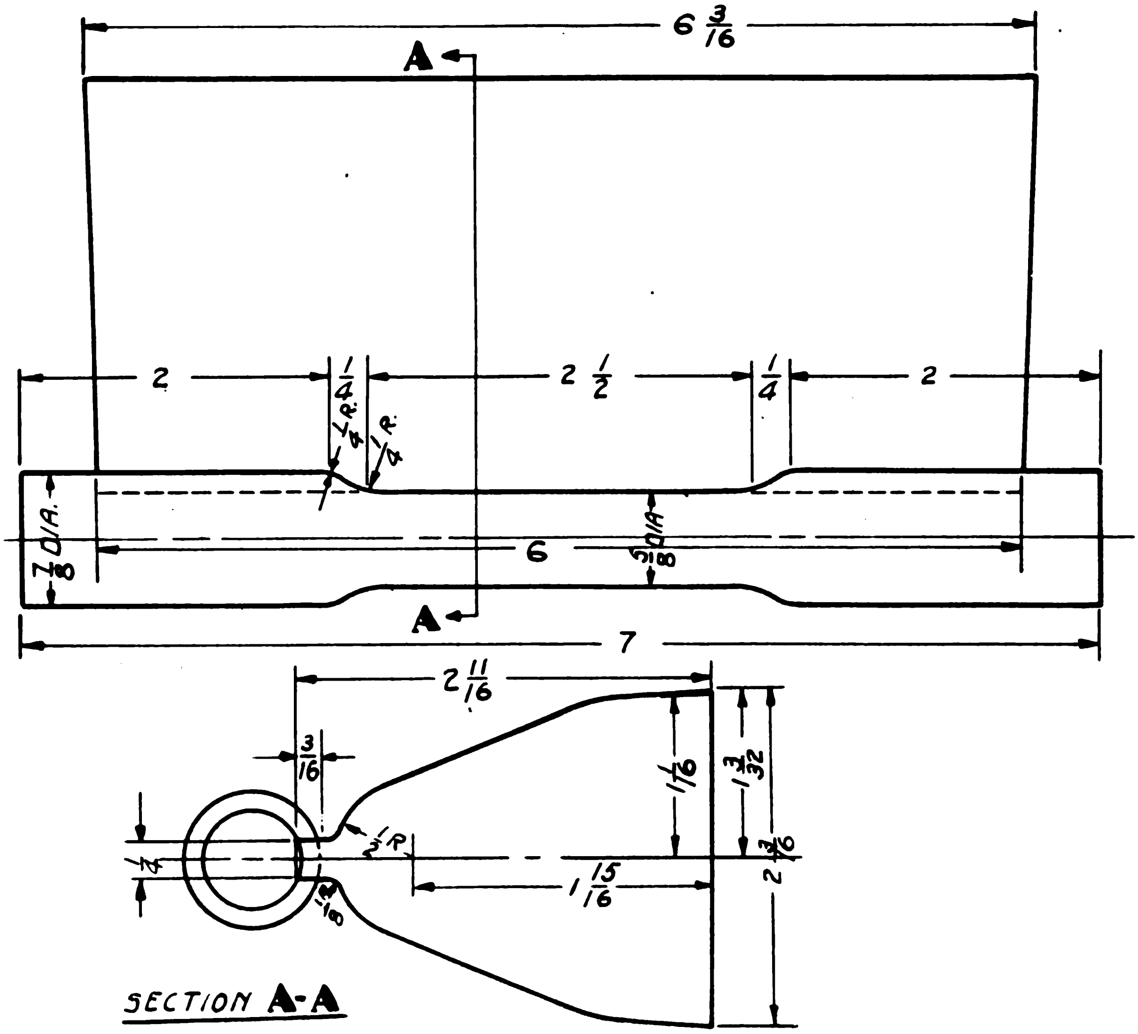


FIG. 20.—Pattern No. TB-2B.

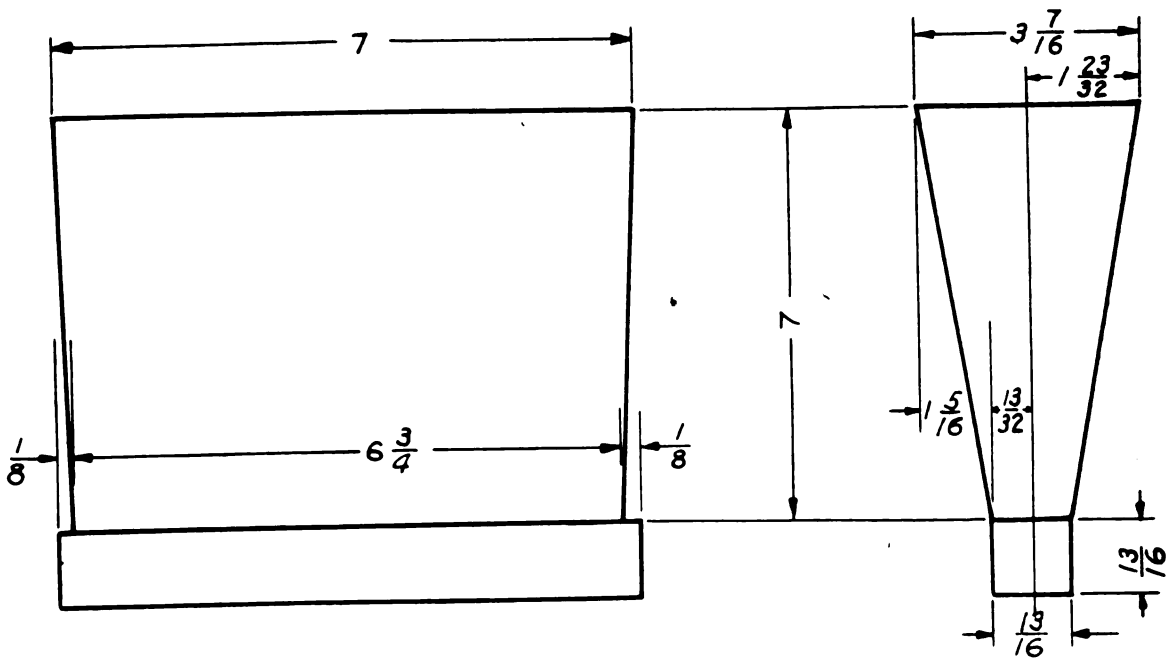


FIG. 21.—Pattern No. TB-2S.

File D 52.416/9/Pt. II

McCOOK FIELD REPORT, SERIAL No. 1950

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | November 1, 1922 | No. 383

THE EFFECT OF DOPED FUELS ON THE FUEL SYSTEM

PART II

(MATERIAL SECTION REPORT No. 173)

▽

Prepared by
A. C. Zimmerman
Engineering Division, Air Service
McCook Field, Dayton, Ohio
June 6, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

THE EFFECT OF DOPED FUELS ON THE FUEL SYSTEM.

PART II.

GENERAL.

Reference is made to a previous report (Air Service Information Circular, Vol. IV, No. 308) by the Material Section, Engineering Division, Air Service, with the same title, dated September, 1921, in which the following conclusions were drawn:

It is found—

(*a*) That the following metals are very slightly, if at all, affected by doped fuels:

Aluminum.	Zinc.

(*b*) That the following materials were very badly affected by such fuels:

Copper.	Terneplate.
Brass.	Iron.

(*c*) That tin plate is moderately attacked by those fuels.

(*d*) It is expected, therefore, that considerable difficulty will be experienced with terneplate tanks, copper lines, brass jets, liners, etc., while aluminum and zinc would overcome this difficulty to a great extent.

The above report covered some of the materials of interest in connection with the effect of doped fuels on the materials in the fuel system. Further data have been included herein according to the suggestion of the Power Plant Laboratory.

PURPOSE.

The purpose of this investigation was to give a more complete idea of the corrosive effect of various doped fuels on materials used or proposed for use in the fuel systems.

CONCLUSIONS.

Conclusions were first drawn on the effect of the various fuels without the addition of a small amount of water to the fuels.

It is found—

(*a*) That the following materials are very slightly, if at all, affected by doped fuels:

Armco iron.	Zinc.
Duralumin.	Tin.
Aluminum.	Red fiber.

(*b*) That the following materials are very badly affected by such fuels:

Lead-clad.	Cork.
Copper.	Vellum.
Brass.	Iron.

(*c*) That the following materials are only slightly affected by these fuels:

Leather.	Monel metal.
Textoil.	

In order to simulate more closely the conditions in the fuel system, a small amount of water was added to the fuels which changed the order of the foregoing conclusions as follows:

Red fiber... Tin........	Very slightly, if at all, affected.
Aluminum.. Duralumin.. Monel....... Textoil..... Leather.....	Slightly affected.
Cork....... Copper..... Brass........ Iron........ Zinc........ Armco....... Vellum...... Lead-clad...	Badly affected.

MATERIAL.

The materials used in this investigation were determined by the Power Plant Laboratory, fuel systems branch. Lead-clad was added to the list in order to compare it with those suggested.

As far as possible, all materials were obtained in sheet form and cut into strips ½ inch wide and 4 inches long. These were partly immersed in the fuels in stoppered bottles.

The following materials were tested with the monoethylaniline 7 per cent plus aviation gasoline 93 per cent solution:

Cork.	Lead-clad.
Duralumin.	Copper.
Textoil.	Brass.
Vellum.	Tin plate.
Monel metal.	Zinc plate.
Leather.	Aluminum.
Red fiber.	Steel.
Armco.	

The following materials were exposed to the action of aviation gasoline alone, 50-50 per cent gasoline-benzol mixture, 91-9 per cent gasoline-antiknock No. 1, and 93-7 per cent gasoline-monoethylaniline:

Lead-clad.	Leather.
Red fiber.	Vellum.
Monel metal.	Duralumin.
Textoil.	Cork.
Armco.	

The aviation gasoline (fig. 1) and benzol were obtained from stock at McCook Field. The doped fuels were furnished by the Power Plant Laboratory, from the General Motors Corporation, research division, at Moraine City.

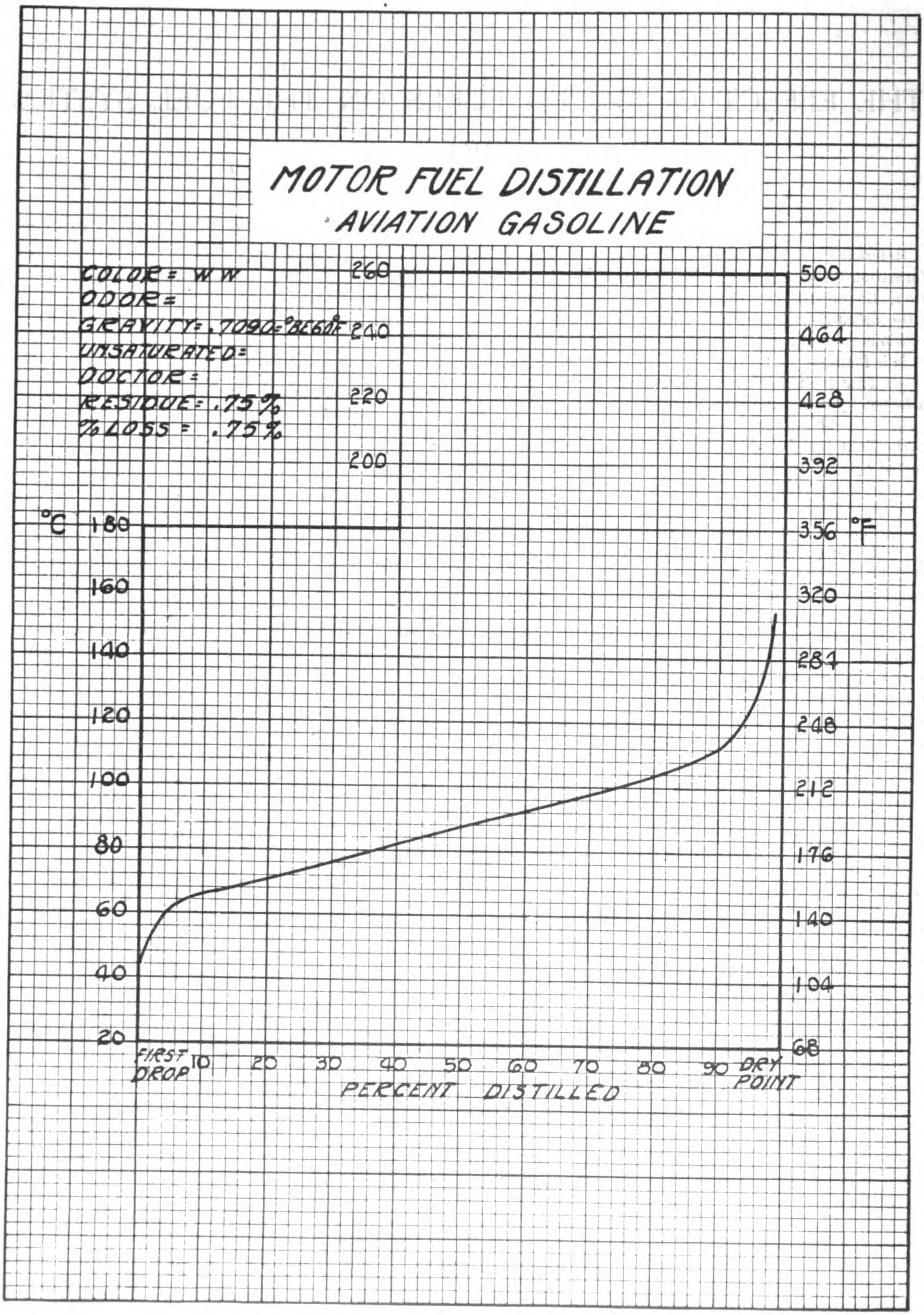

MOTOR FUEL DISTILLATION
AVIATION GASOLINE
COLOR = W.W
ODOR =
GRAVITY = .7090 = °BE 60°F
UNSATURATED =
DOCTOR =
RESIDUE = .75%
% LOSS = .75%
°C
°F
260
240
220
200
180
160
140
120
100
80
60
40
20
500
464
428
392
356
320
284
248
212
176
140
104
68
FIRST DROP
10
20
30
40
50
60
70
80
90
DRY POINT
PERCENT DISTILLED

Fig. 1.

METHOD OF PROCEDURE.

In all cases the materials were cut into strips ½ inch wide and 4 inches long, the thickness varying according to that obtainable in stock. These were placed in the above fuels in such a manner that only half of the specimen was immersed in the liquid, the other half being exposed to atmosphere saturated with the vapors of each fuel. The flasks were securely stoppered so as to exclude the possibilities of ventilation or evaporation, thereby simulating very closely a partially filled gasoline tank. After such data had been obtained from these exposures, 25 c. c. of distilled water was added and the materials again exposed.

RESULTS.

The results obtained from the water-free exposures are shown in Table No. 1.

DISCUSSION OF RESULTS.

In Table No. 1 materials are listed in accordance with the amount of corrosion or deterioration shown. Those at the top of the list were least affected, while those at the bottom were badly affected. This arrangement was brought about by noting the color changes on the specimen above and below the surface of the fuel, by the amount of sediment formed on the bottom of the container, and by simple tests on the strength and elasticity, as in the case of cork, leather, and vellum.

The fact that Textoil does not hold its place among the best materials is due only to the fact that a small amount of sediment was noted in each case. This might have been because it was necessary to expose so much of the raw edges; visibly no discoloration was evidenced. For this reason it is thought that if it could be used where raw edges do not come in contact with the fuels it will stand up well.

As stated in the conclusions, Armco iron shows no signs of corrosion in the fuel alone or in the presence of water when an amine dope is used, but when this class of dope is not added a rapid and excessive formation of ferric hydroxide is noted. The unexpected effect of the amine doped fuels in that it prevented the corrosive effect of the water is explained as follows:

Since the amines are derivatives of ammonia and their properties are somewhat similar it might be expected that the highly ionized carbonic acid in the water would be neutralized by them, thereby preventing the following reactions:

$$Fe+H_2CO_3 \rightarrow FeCO_3+2H$$
$$FeCO_3+H_2O \rightarrow Fe(OH)_2+CO_2$$

Since Armco is so badly affected by water in ordinary fuels, and since water generally finds its way into the various parts of the fuel system, it must lose its place among the least affected materials.

Vellum does not appear to lose its toughness in the fuels, but the doped fuels stained it badly. Water present, however, destroys the toughness of this material.

Lead-clad and alloys containing lead to any extent seem to be greatly affected by all the fuels used in the tests.

Zinc likewise drops to the position of the badly affected materials when immersed in water.

TABLE No. 1.

Material.	Days exposure.	High-test gasoline.	9 per cent antiknock and 91 per cent high-test gasoline.	7 per cent monoethylaniline and 93 per cent high-test gasoline.	50 per cent benzol and 50 per cent high-test gasoline.
Armco	47	O. K.	O. K.	O. K.	O. K.
	78	O. K.	O. K.	O. K.	O. K.
	104	O. K.	O. K.	O. K.	O. K.
Duralumin	47	O. K.	O. K.	O. K.	O. K.
	78	O. K.	O. K.	O. K.	O. K.
	104	O. K.	O. K.	O. K.	O. K.
Aluminum	47			O. K.	
	78			O. K.	
	104			O. K.	
Zinc	47			O. K.	
	78			O. K.	
	104			O. K.	
Tin	47			O. K.	
	78			O. K.	
	104			O. K.	
Red fiber	47	O. K.	O. K.	O. K.	O. K.
	78	O. K.	O. K.	O. K.	O. K.
	104	O. K.	O. K.	O. K.	O. K.
Leather	47	O. K.	O. K.	Slight stain	O. K.
	78	O. K.	Slight stain	do.	O. K.
	104	O. K.	do.	do.	Slight stain.
Textoil	47	O. K.	O. K.	O. K.	O. K.
	78	Slight disintegration	Slight disintegration	Slight disintegration	Slight disintegration.
	104	do.	do.	do.	Do.
Monel	47	O. K.	Slight deposit	Slight deposit	O. K.
	78	O. K.	do.	do.	O. K.
	104	O. K.	do.	do.	O. K.
Iron	47			do.	
	78			Deposit	
	104			do.	
Vellum	47	O. K.	Badly stained	Stained	O. K.
	78	O. K.	do.	Badly stained	O. K.
	104	O. K.	do.	do.	O. K.
Cork	47	O. K.	Slight stain	O. K.	Stained.
	78	O. K.	do.	Slight stain	Do.
	104	O. K.	Stained	do.	Disintegrated.
Brass	47			Deposit	
	78			do.	
	104			do.	
Copper	47			do.	
	78			do.	
	104			do.	
Lead-clad	47	Stained	Stained	Slight stain	Slight stain.
	78	Disintegrated	Disintegrated	Disintegrated	Disintegrated.
	104	do.	do.	do.	Do.

McCOOK FIELD REPORT, SERIAL No. 1960

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | November 1, 1922 | No. 384

EFFECT OF CLIMATE ON STANDARD AIRPLANE-WING COVERINGS

(MATERIAL SECTION REPORT No. 177)

▽

Prepared by C. J. Cleary and G. P. Young
Engineering Division, Air Service
McCook Field, Dayton, Ohio
June 28, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

EFFECT OF CLIMATE ON STANDARD AIRPLANE-WING COVERINGS.

PURPOSE.

The purpose of this series of experiments is to determine the relative suitability of various doping schemes, using standard doping materials, in the different climates represented by the locations of the following stations:

McCook Field, Dayton, Ohio.
France Field, Panama.
March Field, Calif.
Fort St. Michael, Alaska.
Fort Gibbon, Alaska.
Naval Air Station, Hampton Roads, Va.

The original selection of stations also included Texas and the Philippines, but through some difficulty at these points the exposure panels were not returned for test.

CONCLUSIONS.

Any pigmented protective covering is better than a clear dope or clear dope and varnish.

Pigmented dopes are superior to enamels with special reference to aging and weathering properties.

Coatings of clear dope, with or without a finishing coat of clear varnish, are the least satisfactory of all covering schemes tried.

Clear nitrate or clear acetate dopes give equally satisfactory results when used in conjunction with a pigmented protective coating.

The most severe climates of any included in the above list of stations are Panama; Dayton, Ohio; and Norfolk, Va.

MATERIAL.

The material used for covering was standard grade "A" cotton fabric having the following physical properties:

Threads per inch.		Tensile strength.		Weight per square yard (ounces).	Thread size.	
Warp.	Filling.	Warp.	Filling.		Warp.	Filling.
80	80	80	80	4.2	60/2	60/2

No linen fabric was used for the reason that former experiments indicated the superiority of cotton fabrics, especially over a period of exposure to the weather.

There were 12 doping schemes used and 4 panels of each scheme to permit of samples being submitted after continuous exposures of one month, three months, four months, and six months. Each station received one complete set of 48 panels, and the proper panels were forwarded to Dayton at the end of each exposure period. All tests were made in the laboratory of the Engineering Division, Dayton, Ohio.

Below are given formulas, trade names, and manufacturers' names of the various dopes, enamels, and pigmented dope used in this test:

CLEAR CELLULOSE ACETATE DOPE.

The clear cellulose acetate dope, four coats of which were applied in series A, C, D, G, H, I, J, K, and the third, fourth, and fifth coats of series L was United States standard No. 5 dope, code No. 32, manufactured by the Standard Varnish Co., of Staten Island, N. Y., and of the following formula:

Methyl acetate	per cent..	60
Methyl ethyl ketone	do....	10
Benzol	do....	15
Acetone	do....	9
Diacetone alcohol	do....	6
Cellulose acetate	ounces per gallon..	9
Triphenylphosphate	do....	1.15
Benzyl acetate	do....	.4
Benzyl benzoate	do....	.8
Urea	do....	.25

CLEAR CELLULOSE NITRATE DOPE.

The clear cellulose nitrate dope, four coats of which were applied in series B, E, F, and the first and second coats of series L, was du Pont No. 40, code No. 23, manufactured by the E. I. du Pont de Nemours & Co., 120 Broadway, New York City.

LIGHT ENAMEL.

The light enamel used for a finishing coat in series C, E, and L was gray wing enamel, manufactured by the John Lucas Co. (Inc.), Philadelphia, Pa. This was submitted through the Navy Department as the standard wing enamel used by them.

DARK ENAMEL.

The dark enamel used for a finishing coat in series D and F was olive-brown wing enamel "B," manufactured by the Glidden Co., Cleveland, Ohio.

KHAKI PIGMENTED NITRATE DOPE.

The khaki pigmented nitrate dope, two coats of which were used as finishing coats in series G, was Air Service pigmented covering No. 106, code No. 7, developed and manufactured by the Air Service, and of the following formula:

	Pounds.
Venetian red	1.20
Ultramarine blue	9.35
Yellow ochre	55.50
Castor oil	33.95
Paste to each 10 pounds clear du Pont No. 40 nitrate dope	1.9

RED PIGMENTED NITRATE DOPE.

The red pigmented nitrate dope, two coats of which were used as finishing coats in series F, was known as Air Service insignia, red, code No. 9, developed and manufactured by the Air Service, and of the following formula:

	Pounds.
Vermilion deep	83.3
Castor oil	16.7
Paste to each 10 pounds clear dope	1.5

WHITE PIGMENTED NITRATE DOPE.

The white pigmented nitrate dope, two coats of which were used as finishing coats in series I, was known as Air Service insignia, white, code No. 8, developed and manufactured by the Air Service, and of the following formula:

	Pounds.
Zinc oxide	77.8
Castor oil	22.2
Paste to each 10 pounds clear dope	1.0

BLUE PIGMENTED NITRATE DOPE.

The blue pigmented nitrate dope, two coats of which were used as finishing coats in series J, was code No. 2, identification color "blue," manufactured by the Titanine (Inc.) Union, N. J.

ALUMINIZED NITRATE DOPE.

The aluminated nitrate dope, two coats of which were used as finishing coats in series K, was used in formula of 1 pound powdered aluminum and 7 pounds du Pont 40 nitrate dope.

NAVY DOPING SCHEME.

The panels in series L were doped in accordance with the Navy doping scheme, which consisted of two coats of nitrate dope, du Pont No. 40, three coats of clear acetate, and two coats of gray enamel. The general idea of this scheme was to obtain the necessary tautness by the use of the nitrate dope and to get some slight degree of fireproofing by the use of the acetate dope.

PROCEDURE OF TESTS.

Exposure panels, 12 by 12 inches inside dimensions, were covered on the face and back with cotton fabric. The doping schemes used were as follows:

A. Clear acetate.
B. Clear nitrate.
C. Clear acetate with light enamel.
D. Clear acetate with dark enamel.
E. Clear nitrate with light enamel.
F. Clear nitrate with dark enamel.
G. Clear acetate with pigmented nitrate, khaki.
H. Clear acetate with pigmented nitrate, red.
I. Clear acetate with pigmented nitrate, white.
J. Clear acetate with pigmented nitrate, blue.
K. Clear acetate with aluminized nitrate.
L. Clear nitrate, clear acetate with light gray enamel (Navy scheme).

Four panels for each series were made for the purpose mentioned above. After the samples were completed and had dried for twenty-four hours, tautness measurements were made on each panel for use as a reference in measuring the tautness life of each covering.

The directions for exposing these panels were as follows: "A rack or frame should be built to permit the panels to face the south, and they should be at an angle of 45° from the horizontal. The side of the panel on which the metal tag is attached should be up at all times."

As each series was completed, each panel was tested, face and back, to determine (*a*) the tautness of the covering, (*b*) the tensile strength, (*c*) the tearing resistance, and (*d*) a visual and manual inspection of the condition of the covering.

APPARATUS.

Tautness measurements were made by the use of a McGowan tautness meter, which consists of a span the width of the rib spacing. This span has an Ames dial gauge fastened at the center. Known weights can be placed upon the gauge plunger and the deflection due to these weights is indicated on the gauge face. The three arbitrary weights are:

1. The plunger alone.
2. The plunger plus 3 ounces.
3. The plunger plus 24 ounces.

In making tautness determinations, using these weights a hysteresis diagram is developed which indicates the degree of tautness and the amount of "set" in the covering material. Visual and manual inspections were made by the operator.

SCOTT TEXTILE TESTING MACHINE.

All tensile strength and tearing resistance determinations were made, using an H. L. Scott vertical textile testing machine.

TORSION BALANCE.

All weight determinations were made, using a standard torsion balance.

RESULTS OF TESTS.

TENSILE STRENGTH.

Tensile strength determinations on samples which were exposed at the several fields are included in Table 1. The decrease in strength is noted for each sample over the entire exposure period for each station. A study of this strength loss will give a fair idea of the comparative severity of the climate at each station.

TAUTNESS DETERMINATIONS.

All tautness determinations were made, using a McGowan tautness meter, which is described above. In principle, this apparatus is correct, but when using wooden frames which have been exposed over the entire exposure period, the tautness determinations obtained are doubtful owing to the warping of the wood in the panels. Table 2 is offered, however, to show the general tendencies of the various coatings as indicated when using the above meter.

UNIT WEIGHTS OF WING COVERINGS.

The question of unit weight of wing coverings is of some importance to the designer and the manufacturer. Table

3 shows the original weights of the coverings before exposure and the weights of the same coverings after a continuous exposure of six months.

The clear nitrate dope was completely washed off as a result of six months' exposure, and the weight of the coating after exposure, as noted above, is the weight per square yard of the fabric alone. The weight of both panels, using light enamel as a finishing coat, was reduced mainly due to the fact of the enamel flaking off the doped surface, and the final weight as reported above is approximately the weight of the fabric plus the clear dope. The panel having a finishing coat of aluminized nitrate apparently increased in weight. This is believed to be due to the accumulation of dust and dirt, rather than to any properties of this coating.

TEAR RESISTANCE.

A typical group of results showing the effect of the several doping schemes on the tear resistance of standard airplane cotton and the effect of weathering on the tearing resistance of each doping scheme, is shown in Table 4. This table shows only the effect on the tearing strength of the filling for convenience, as the effect on the warp is of essentially the same magnitude and shows the same tendencies.

The tearing tests were made in accordance with the "strip-tear" method, which is as follows: A sample 6 inches long and 2 inches wide was cut down the center for a distance of 2 inches. One strip was placed in the top jaw and the other strip was placed in the lower or pulling jaw of the testing machine. The magnitude of the force necessary to tear this specimen along the direction of the cut was registered on the dial of the machine. The results of these tests are shown in Table 4.

LIFE OF CLEAR DOPE AND SPAR VARNISH COVERINGS.

In order to compare the life and performance of the older type doping scheme—that is, clear acetate dope with a finishing coat of high-grade spar varnish—data were obtained from the files of the Material Section of the Engineering Division regarding the performance of clear dope and clear varnish when exposed to the weather. An approximation of the average service life of these coatings is as follows:

Doping scheme.	Approximate service life.
Raftite and clear spar varnish [1]	1 to 2 months.
United States standard No. 5 and clear spar varnish	2 months.

[1] Raftite is a clear acetate dope developed by the R. A. F. and is the standard British clear acetate dope.

EFFECT OF SUNLIGHT, RAIN, ETC.

In obtaining the effect of sunlight, rain, etc., usually described as weathering, the panels were covered and doped on the face and back in the same manner. These panels were exposed by mounting on a skeleton rack, facing south, the panels raised at an angle of 45°. This condition of exposure was standard for all stations. The face, consequently, was exposed to the effects of sunlight, rain, temperature, and humidity changes, while the back or under side was exposed only to changes of temperature and humidity. In Table 5, the effect of sunlight, etc., on the face is shown over the entire exposure period by the tensile strength results, and the tensile strength of the back or under side over the entire exposure period shows the effect of protecting the doped coating from the weather. The values reported above are composite for all stations for each doping scheme over the same period of exposure. Each value indicated in Table 5 was obtained as follows: The results of tensile-strength determinations on the face fabric of each doping scheme for corresponding periods of exposure for all stations were grouped and the mean value taken as indicating the average strength result which might be expected of that particular doping scheme for the indicated length of exposure. The values for the back fabric were obtained in the same manner. It is felt that this average is a truer criterion of performance than if the results of tests on panels from only one station were reported.

CONDITION OF PANELS.

Before making detailed tests on exposed panels, notes were made on the physical appearance of each panel. It is not considered necessary to make a complete list of notes for each station for each exposure period. The relative weathering characteristics of the several doping schemes were approximately the same for each station, the only difference being one of degree of failure. The following notes were made after six months' exposure of one complete set of panels at McCook Field. The condition of each panel at the start of the test was equal to the best production finish which could be obtained for a similar doping scheme.

Clear acetate	Face: Film failure; poor. Back: No failure; good.
Clear nitrate	Face: Dope completely washed off. Back: No failure; good.
Acetate and light enamel	Face: Enamel flaked off; dope good. Back: Enamel flaked slightly; dope good.
Acetate and dark enamel	Face: Good condition, Back: Good condition.
Nitrate and light enamel	Face: Enamel flaked off; dope good. Back: Enamel flaked slightly; dope good.
Nitrate and dark enamel	Face: Good condition. Back: Good condition.
Acetate and pigmented nitrate, khaki.	Face: Good condition. Back: Good condition.
Acetate and pigmented nitrate, red.	Face: Good condition. Back: Good condition.
Acetate and pigmented nitrate, white.	Face: Pigment cracks on bending. Back: Pigment cracks on bending.
Acetate and pigmented nitrate, blue.	Face: Good condition. Back: Good condition.
Acetate and aluminized nitrate.	Face: Good condition. Back: Good condition.
Navy scheme	Face: Enamel flaked slightly; dope good. Back: Enamel flaked slightly; dope good.

DISCUSSION OF RESULTS.

The effect of weathering upon the different doping schemes can be visualized more clearly by using Figure 1 in conjunction with Table 1. The table gives the detailed tensile strength results from the panels of each station for each doping scheme. Figure 1 shows composite curves for all exposure stations for each doping scheme.

From Table 1 it is seen that the effect on the clear acetate and clear nitrate dopes without any protective covering is considerably more than the effect on the schemes having a pigmented protective covering of whatever description. It can also be seen from Table 1 that the climates of Dayton, Panama, and Virginia have the most severe effect on the performance of all dope coatings.

Figure 1, showing composite curves for each doping scheme, indicates (1) that six months' exposure is not sufficiently long to give complete life data on all of the schemes. It does, however, show marked tendencies in most cases. A second point shown by this figure is that any doping scheme using a pigmented protective covering of any description is superior to a scheme using a clear dope with or without a clear finishing coat.

The standard Air Service doping scheme, curve G, and the aluminized nitrate doping scheme, curve K, show performance and life characteristics superior to all other doping schemes. The standard covering, curve G, is heavier per unit area than the aluminized dope, but the latter is not a mat surface.

The schemes using a finishing coat of dark enamel on either clear acetate or clear nitrate dope, represented by curves D and F, are slightly superior to those using a finishing coat of light enamel (curves C and E). It is believed, however, that this difference is due entirely to relative quality of the light enamels and the dark enamels.

The strength and performance of the panel doped in accordance with the Navy scheme is about equal to those panels having a dark enamel finishing coat.

On Figures 1, 2, and 3, "Zone of complete failure," this limit was taken from a German report in Zeitschrift für Flugtechnik und Motorluftschiffart, Fr. Wendt, in which he concludes that the danger point in airplane-fabric performance is when the fabric fails under a load of 700 to 800 kilograms per meter (40 to 45 pounds per inch). This is used for convenience in showing the life limits of the various doping schemes.

In general, the outstanding features of performance of doping schemes show that a pigmented protective coating on a clear dope is more satisfactory than a clear dope alone, and that a pigmented dope is slightly superior to an enamel finishing coat.

Figure 2 shows a comparison of the weathering effect on those schemes using light or dark enamel as finishing coats. It is concluded from these curves that either nitrate or acetate clear dope and either light or dark enamel will give equally satisfactory weathering results, provided that the clear dopes and the enamels are made of high-grade materials and are of good quality.

Figure 3 shows a comparison of the weathering effect on the clear acetate panels and the clear nitrate panels. No varnish was used on these panels as a finishing coat. The life and performance of each is unsatisfactory, but the clear nitrate more so than the clear acetate.

CLEAR ACETATE AND CLEAR NITRATE DOPES WITH PIGMENTED PROTECTIVE COVERINGS.

No marked difference in performance is evidenced between the use of clear nitrate or clear acetate dope when used with a pigmented protective covering. A consideration of Tables 1, 2, 4, and 5, and figures 1 and 2 show no superiority on the part of either nitrate or acetate dope when protected from the action of sunlight.

TAUTNESS DETERMINATIONS.

The tautness determinations were made on several complete series of panels, with the idea of showing the life of the dope coating by changes in the slope of the curve obtained as described under "Procedure of tests." It was also hoped to obtain some information regarding tautness from a study of the hysteresis loops at various stages of exposure by the use of a tautness meter. These tests were not entirely satisfactory for several reasons, chief of which was that six months' exposure did not cause sufficient failure of any but the clear dope panels to show any great changes in the slopes of the curves or any great increase in the area of the hysteresis loops developed. The second reason was that, due to warping of the wooden frames used, the readings were not altogether reliable. It is believed also that tautness readings on doped wing coverings in service would be equally unreliable as a result of warping of wooden members or loosening of glued joints. Tautness determinations may have some value in the laboratory only when using some form of panel having permanent dimensions and not subject to warping or other effects causing distortion.

UNIT WEIGHTS.

Considerable variation in unit weights is shown between the various doping schemes. The clear dopes, as might be expected, are considerably lighter in weight than the other coatings having pigmented protective coverings, but their performance under weathering precludes the necessity of considering them in this discussion. Those panels having an aluminized pigmented dope or finishing coat of dark enamel are the lightest and most desirable from the designer's standpoint. The lack of uniformity in the quality of the enamels and their relatively higher price as compared with pigmented dope are the two factors which militate against the use of khaki enamel as a finishing coat. The glossy surface of the enamel is considered to be bad by some pilots, but there is not a unanimity of opinion on this point. This glossiness disappears on weathering. Another factor not previously discussed in this paper is the application of enamel under production conditions. This is more difficult than the application of a pigmented dope and the drying time is much longer.

All pigmented dope samples, except the aluminized dope, are heavier than the clear dope and dark enamels. The light enamels are as heavy as pigmented dope, due probably to the nature of the pigment used, but their weathering characteristics are unsatisfactory.

All pigmented dopes weather excellently, and while the aluminized dope can be considered ideal from a weight standpoint and a sky camouflage, it is desirable to use the other pigmented dope on account of the necessity for a khaki color for ground camouflage and red, white, and blue for insignia.

TEARING RESISTANCE.

One of the most vital properties of a doped fabric is its performance when torn. A general consideration of the theory of doping to obtain maximum tearing resistance is relevant at this point. Considering the test method known as the "strip-tear" method, where each consecutive thread is subject to shear, the maximum tearing resistance might be expected from undoped fabric. In this case the threads of the fabric can bunch up in the region of the tear, which effect is called "fabric assistance," and the maximum resistance to tearing is obtained. When the fabric is doped and the dope thoroughly brushed in, restraining each thread in its relative position, the tearing test resolves itself into what is essentially a shear of consecutive threads in the fabric with the minimum or no "fabric assistance". From this it can be seen that the diameter of the individual thread in the fabric is a function of the tearing resistance, and also that the tearing resistance varies directly as the diameter of the yarn.

The ideal condition to strive for in a doped fabric is to obtain a dope film which will break away from the fabric at the region of greatest stress when a tear starts. One way to help at arriving at this condition is not to brush in the dope film too thoroughly when doping. Any other effect obtained will be due to inherent qualities in the dope film itself.

Table 4 gives the values for tearing resistance as determined on one complete set of panels. These values are typical for each complete set, and the performace of the pigmented dope is consistently better than the enamels and clear dope in every case.

LIFE OF COVERINGS USING CLEAR DOPE AND CLEAR SPAR VARNISH.

The life of clear dope with a clear varnish finishing coat, as shown under "Results of tests," shows no great improvement in life over clear dope without the varnish, and both methods can be considered as unsatisfactory.

EFFECT OF SUNLIGHT, RAIN, ETC.

Table 5 gives detailed results showing the effect of sunlight, rain, etc. on the upper face of the panels, and the properties of the under side of the panels show the effect of protection which can be expected upon the under side of airplane wings or experimental panels.

Figure 4 shows graphically the degree of protection afforded by the various types of coverings used. All coverings using a pigmented protective coating of any description are superior to the clear coverings. The light enamels are inferior to the dark enamels and pigmented dopes, and are superior to the clear dopes. The superiority of the dark enamels and pigmented dopes over the light enamels is not believed to be due to any special properties of the pigments themselves, but is rather a difference in quality between enamels. It is plainly evident from this that some form of pigmented protective covering is much more desirable in all cases than any form of clear covering. The rate of decrease in tensile strength is also greatly in favor of pigmented dope coverings, which is of considerable importance from the standpoint of airplane maintenance.

CONDITION OF PANELS AND COVERINGS.

In general, the physical condition of the Panama samples was the worst as a result of mildew growth and water rotting. The rainfall and humidities at Panama are excessive, which will explain this condition.

The Dayton and Virginia panels show the next most severe exposure conditions, and the remaining panels show no great difference between themselves and are the least affected.

Considering the different schemes from all groups, the observer was able to classify each scheme in the following order, with reference to desirability as a service coating:

1. Pigmented dopes, including the aluminized dope.
2. Dark enamel finish.
3. Navy doping scheme.
4. Light enamel finish.
5. Clear dope and clear varnish.
6. Clear dopes.

TABLE 1.—*Tensile strength of doped fabrics over weathering period.*

Station.	Dope.	Original.		One month.		Three months.		Four months.		Six months.		Loss in strength over 6 months, per cent.	
		Warp.	Fill.	Warp.	Fill.	Warp.	Fill.	Warp.	Fill.	Warp.	Fill.	Warp.	Fill.
Dayton, Ohio	Clear acetate, scheme "A".	97	111	84	96	81	91	71	94	42	62	−57	−44
Panama				73	91	50	61	40	10	26	45	−73	−77
California				86	100	62	91	61	67	41	59	−58	−47
St. Michael, Alaska				98	107	78	103	80	94	79	97	−19	−13
Fort Gibbon, Alaska				101	119	99	119	91	108	76	97	−22	−13
Norfolk, Va				85	101	67	81	40	70	42	70	−57	−37
Average												−48	−39
Dayton, Ohio	Clear nitrate, scheme "B".	89	110	67	93	42	62	22	32	28	25	−69	−76
Panama				82	98	44	28	15	15	14	22	−84	−80
California				49	81	18	29	12	18	10	17	−89	−85
St. Michael, Alaska				99	115	58	87	52	66	41	51	−54	−54
Fort Gibbon, Alaska				98	117	101	112	93	113	39	64	−56	−42
Norfolk, Va				64	87			9	19			−89	−83
Average												−73	−70
Dayton, Ohio	Clear acetate and light enamel, scheme "C."	94	109	86	126	85	115	92	120	44	44	−53	−60
Panama				86	120	43	74	40	68	34	73	−64	−34
California				93	119	93	108	77	86	70	85	−25	−22
St. Michael, Alaska				97	115	97	120	87	102	80	99	−15	− 9
Fort Gibbon, Alaska				90	116	99	113	103	120	82	107	−13	− 2
Norfolk, Va				98	118	76	107	79	99	60	76	−36	−30
Average												−34	−29
Dayton, Ohio	Clear acetate and dark enamel, scheme "D."	90	110	92	117	85	118	88	112	73	84	−19	−24
Panama				88	122	75	109	22	75	71	109	−21	− 1
California				88	115	77	116	66	70	68	104	−24	− 5
St. Michael, Alaska				99	122	104	129	108	108	90	122	0	+10
Fort Gibbon, Alaska				101	119	102	132	98	124	100	120	+11	+ 8
Norfolk, Va				96	118	74	107	82	101	70	99	−22	−10
Average												−13	− 6
Dayton, Ohio	Clear nitrate and light enamel, scheme "E."	89	110	92	104	90	105	94	117	58	75	−35	−32
Panama				92	114	84	104	59	92	65	108	−27	− 2
California				75	125	67	111	51	63	72	102	−19	− 7
St. Michael, Alaska				97	123	93	113	96	127	93	122	+ 4	+10
Fort Gibbon, Alaska				89	115	73	74	61	122	94	122	+ 6	+10
Norfolk, Va				92	122	70	102	66	83	89	90	0	−18
Average												−12	− 7
Dayton, Ohio	Clear nitrate and dark enamel, scheme "F."	97	113	92	114	84	111	82	104	65	66	−33	−42
Panama				95	135	82	110	72	89	74	89	−24	−21
California				93	129	91	115	48	62	66	83	−32	−27
St. Michael, Alaska				102	135	105	124	99	114	89	109	− 8	− 3
Fort Gibbon, Alaska				102	115	102	116	97	121	95	115	− 2	+ 2
Norfolk, Va				92	114	84	105	76	98	78	104	−20	− 8
Average												−20	−17
Dayton, Ohio	Clear acetate and pigmented nitrate, khaki, scheme "G."	101	115	105	147	88	131	99	127	77	83	−24	−28
Panama				92	121	89	110	88	70	88	132	−13	+15
California				93	143	88	131	71	86	87	134	−14	+16
St. Michael, Alaska				113	131	117	120	107	136	99	126	− 2	+ 1
Fort Gibbon, Alaska				109	128	111	135	122	148	98	133	− 3	+14
Norfolk, Va				104	125	99	117			No samples.			
Average												−11	+ 4
Dayton, Ohio	Clear acetate and aluminized nitrate, scheme "K."	97	121	111	119	91	112	101	107	87	63	−10	−48
Panama				93	126	88	99	88	108	45	88	−54	−27
California				97	129	98	117	60	74	96	107	− 1	−12
St. Michael, Alaska				103	115	100	122	90	117	96	117	− 1	− 3
Fort Gibbon, Alaska				90	126	95	115	98	119	108	116	+11	− 4
Norfolk, Va				92	121	90	109	93	113	76	110	−22	− 9
Average												−13	−17
Dayton, Ohio	Navy scheme "L"	94	110	95	118	93	122	96	114	62	79	−34	−23
Panama				No samples forwarded.									
California				90	116	75	113	70	84	74	104	−21	− 5
St. Michael, Alaska				No samples forwarded.									
Fort Gibbon, Alaska				No samples forwarded.									
Norfolk, Va				82	114	90	119	79	107	82	112	−13	+ 1
Average												−23	− 9

TABLE 2.—*Slopes of tautness curves over exposure period.*

Covering.	Original.	One month.	Three months.	Four months.	Six months.
Clear acetate	1.26	1.15	1.05	1.07	.93
Clear nitrate	1.59	1.12	Complete dope failure.		
Clear acetate and light enamel	1.46	1.51	1.56	1.56	1.57
Clear acetate and dark enamel	1.19	1.26	1.21	1.36	1.37
Clear nitrate and light enamel	1.45	1.49	1.81	1.80	1.41
Clear nitrate and dark enamel	1.59	1.23	1.29	1.22	1.43
Clear acetate and pigmented nitrate, khaki	1.79	1.77	2.08	1.84	1.75
Clear acetate and pigmented nitrate, red	1.78	1.67	1.72	1.53	1.86
Clear acetate and pigmented nitrate, white	1.80	1.89	2.00	1.84	1.86
Clear acetate and pigmented nitrate, blue	1.66	1.46	1.64	1.63	1.56
Clear acetate and aluminized nitrate	1.39	1.49	1.57	1.55	1.47
Navy scheme	1.41	1.56	1.78	1.80	1.45

TABLE 3.—*Unit weights of wing coverings.*

Covering.	Original weight, ounces per square yard.	Weight after 6 months' exposure, ounces per square yard.
Clear acetate	6.4	5.7
Clear nitrate	5.6	4.2
Clear acetate and light enamel	9.3	6.1
Clear acetate and dark enamel	6.7	6.8
Clear nitrate and light enamel	9.0	7.1
Clear nitrate and dark enamel	6.7	6.5
Clear acetate and pigmented nitrate, khaki	8.4	8.4
Clear acetate and pigmented nitrate, red	8.3	7.3
Clear acetate and pigmented nitrate, white	9.2	9.0
Clear acetate and pigmented nitrate, blue	8.6	8.4
Clear acetate and aluminized nitrate	6.6	7.0
Navy scheme	9.2	9.0

TABLE 4.—*Tearing resistance.*

Covering.	Period of exposure.			
	One month.	Three months.	Four months.	Six months.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Clear acetate	3.1	3.5	3.0	3.0
Clear nitrate	3.0	2.25	.5	.5
Clear acetate and light enamel	4.5	4.0	4.8	3.5
Clear acetate and dark enamel	4.5	4.5	5.0	3.5
Clear nitrate and light enamel	3.75	3.75	4.0	2.3
Clear nitrate and dark enamel	3.5	4.25	4.0	3.0
Clear acetate and pigmented nitrate, khaki	7.0	5.0	6.0	3.0
Clear acetate and pigmented nitrate, red	3.5	6.0	6.0	3.3
Clear acetate and pigmented nitrate, white	6.0	4.5	6.0	3.3
Clear acetate and pigmented nitrate, blue	4.5	4.5	7.0	3.3
Clear acetate and aluminized nitrate	4.5	5.0	5.0	4.0
Navy scheme	3.5	3.75	5.0	3.0

TABLE 5.—*Effect of sunlight, rain, etc., on doped coverings.*

Covering.		Tensile strength, pounds per inch—Exposure period.							
		One month.		Three months.		Four months.		Six months.	
		Warp.	Fill.	Warp.	Fill.	Warp.	Fill.	Warp.	Fill.
Clear acetate	Face	88	102	73	91	64	74	51	72
	Back	96	113	90	112	78	111	77	100
Clear nitrate	Face	77	65	53	63	34	45	26	38
	Back	99	121	92	109	86	98	71	81
Clear acetate and light enamel	Face	92	119	82	106	80	99	62	81
	Back	96	116	86	121	86	108	83	107
Clear acetate and dark enamel	Face	94	119	86	118	77	98	79	106
	Back	94	120	93	118	83	101	90	116
Clear nitrate and light enamel	Face	90	117	80	102	71	101	75	103
	Back	91	116	88	116	81	105	83	102
Clear nitrate and dark enamel	Face	96	124	91	114	97	98	78	94
	Back	96	122	101	119	97	114	92	114
Clear acetate and pigmented nitrate, khaki	Face	103	133	99	124	97	113	90	122
	Back	108	139	99	124	94	119	97	129
Clear acetate and pigmented nitrate, red	Face	82	130	97	123	88	108	87	112
	Back	104	130	99	127	90	121	97	121
Clear acetate and pigmented nitrate, white	Face	98	125	94	119	84	102	79	103
	Back	104	133	97	122	84	105	85	108
Clear acetate and pigmented nitrate, blue	Face	93	122	89	122	80	106	83	105
	Back	100	118	99	121	87	113	95	118
Clear acetate and aluminized nitrate	Face	98	123	94	113	88	106	85	100
	Back	96	122	100	121	97	114	96	110
Navy scheme	Face	89	115	86	118	82	102	73	98
	Back	96	119	93	119	84	117	80	105

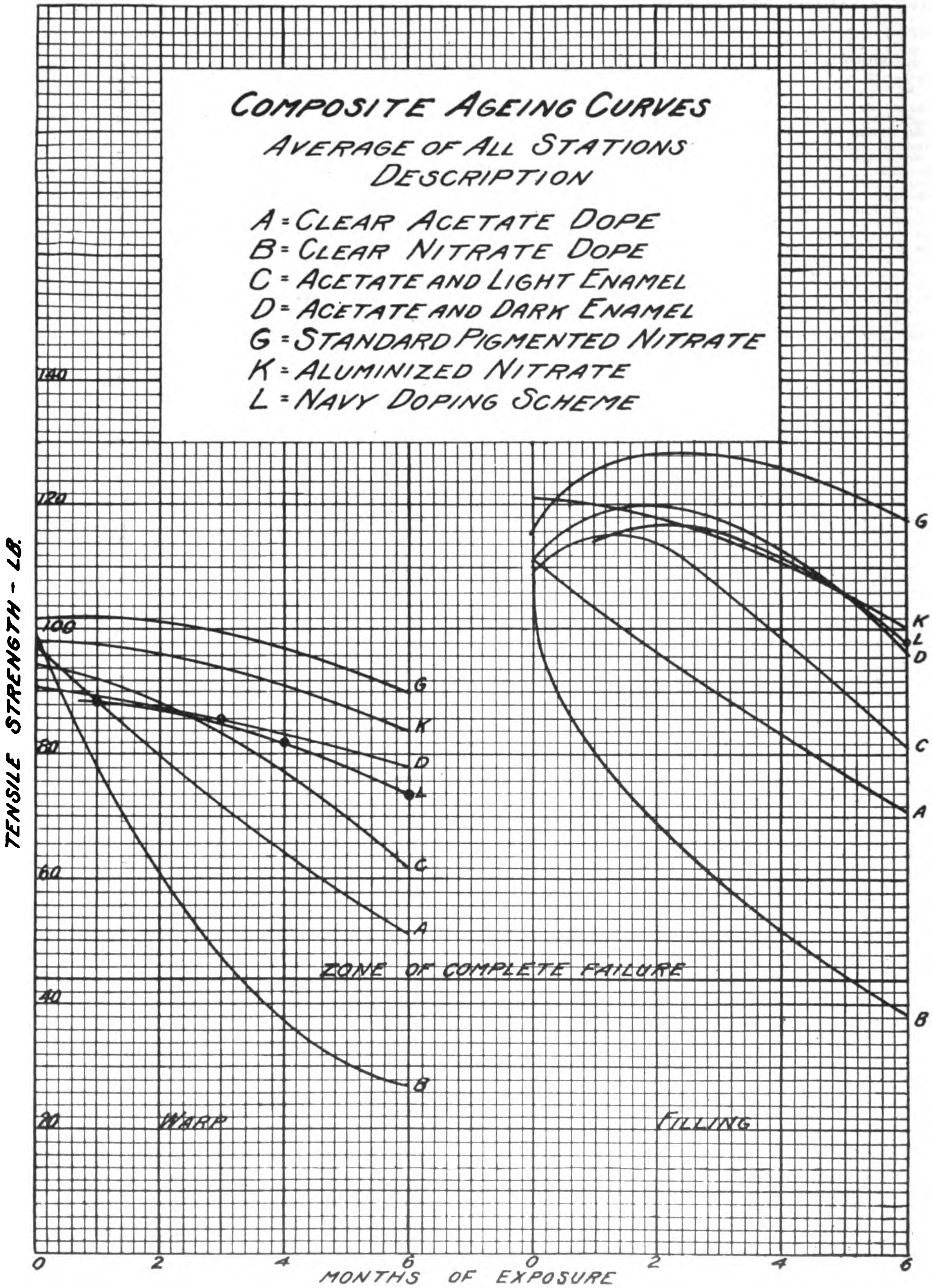

COMPOSITE AGEING CURVES
AVERAGE OF ALL STATIONS
DESCRIPTION
A = CLEAR ACETATE DOPE
B = CLEAR NITRATE DOPE
C = ACETATE AND LIGHT ENAMEL
D = ACETATE AND DARK ENAMEL
G = STANDARD PIGMENTED NITRATE
K = ALUMINIZED NITRATE
L = NAVY DOPING SCHEME
TENSILE STRENGTH - LB.
140
120
100
80
60
40
20
ZONE OF COMPLETE FAILURE
WARP
FILLING
G
K
D
L
C
A
B
0
2
4
6
MONTHS OF EXPOSURE

FIG. 1.

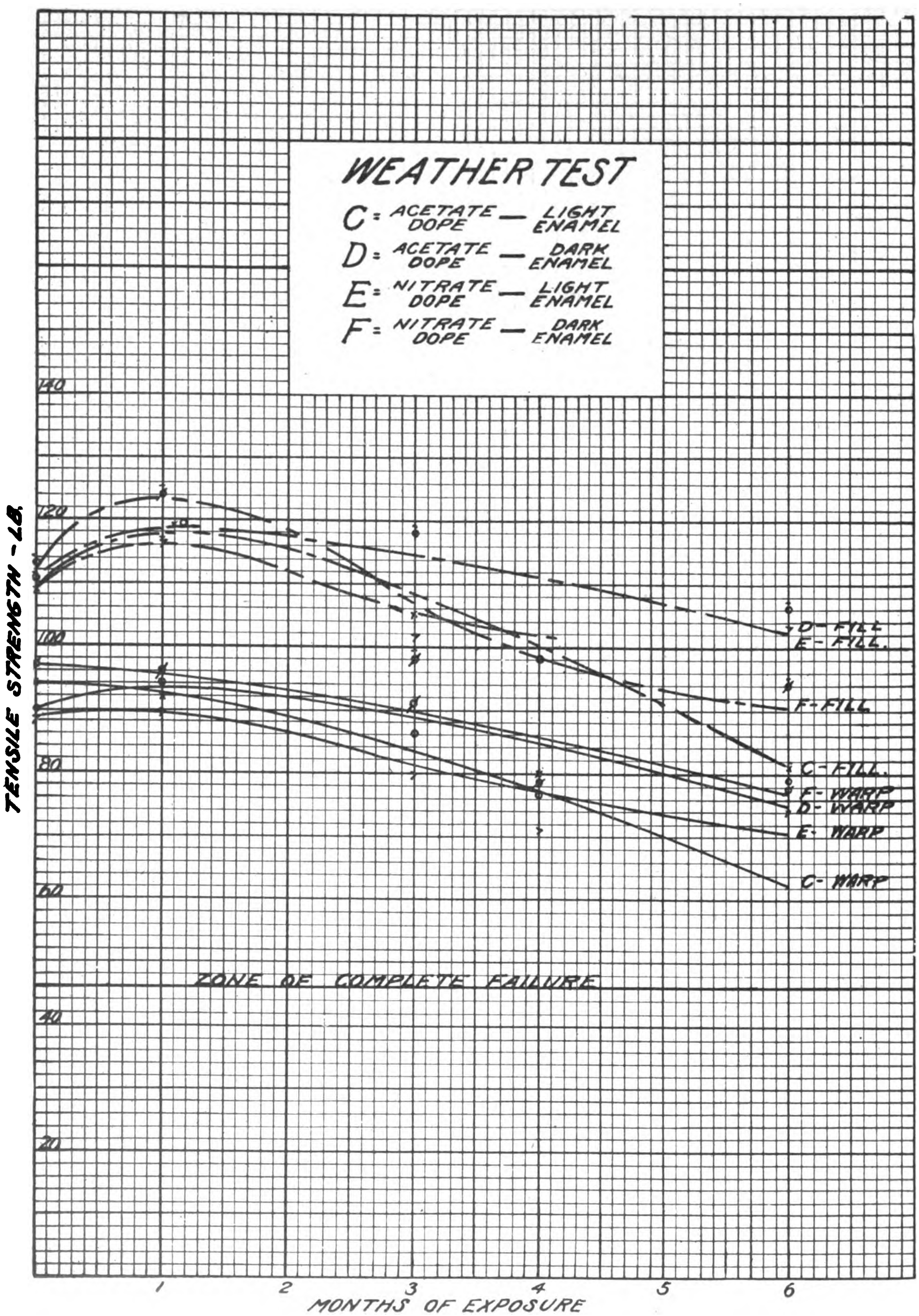

WEATHER TEST
C = ACETATE DOPE — LIGHT ENAMEL
D = ACETATE DOPE — DARK ENAMEL
E = NITRATE DOPE — LIGHT ENAMEL
F = NITRATE DOPE — DARK ENAMEL
140
120
100
80
60
40
20
TENSILE STRENGTH - LB.
D-FILL
E-FILL.
F-FILL
C-FILL.
F-WARP
D-WARP
E-WARP
C-WARP
ZONE OF COMPLETE FAILURE
1
2
3
4
5
6
MONTHS OF EXPOSURE

FIG. 2.

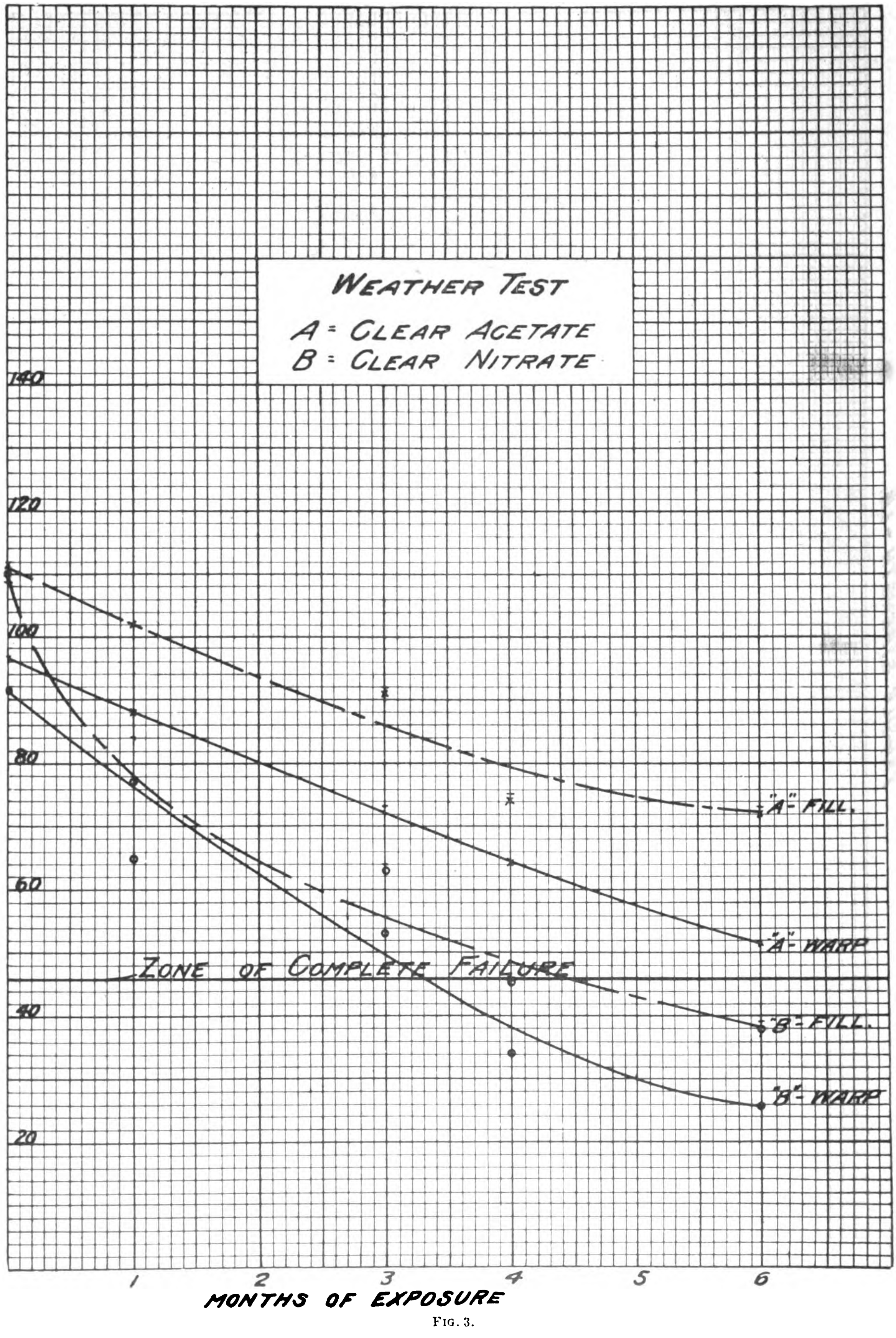

WEATHER TEST
A = CLEAR ACETATE
B = CLEAR NITRATE
140
120
100
80
60
40
20
"A" FILL.
"A" WARP
"B" FILL.
"B" WARP
ZONE OF COMPLETE FAILURE
1
2
3
4
5
6
MONTHS OF EXPOSURE

FIG. 3.

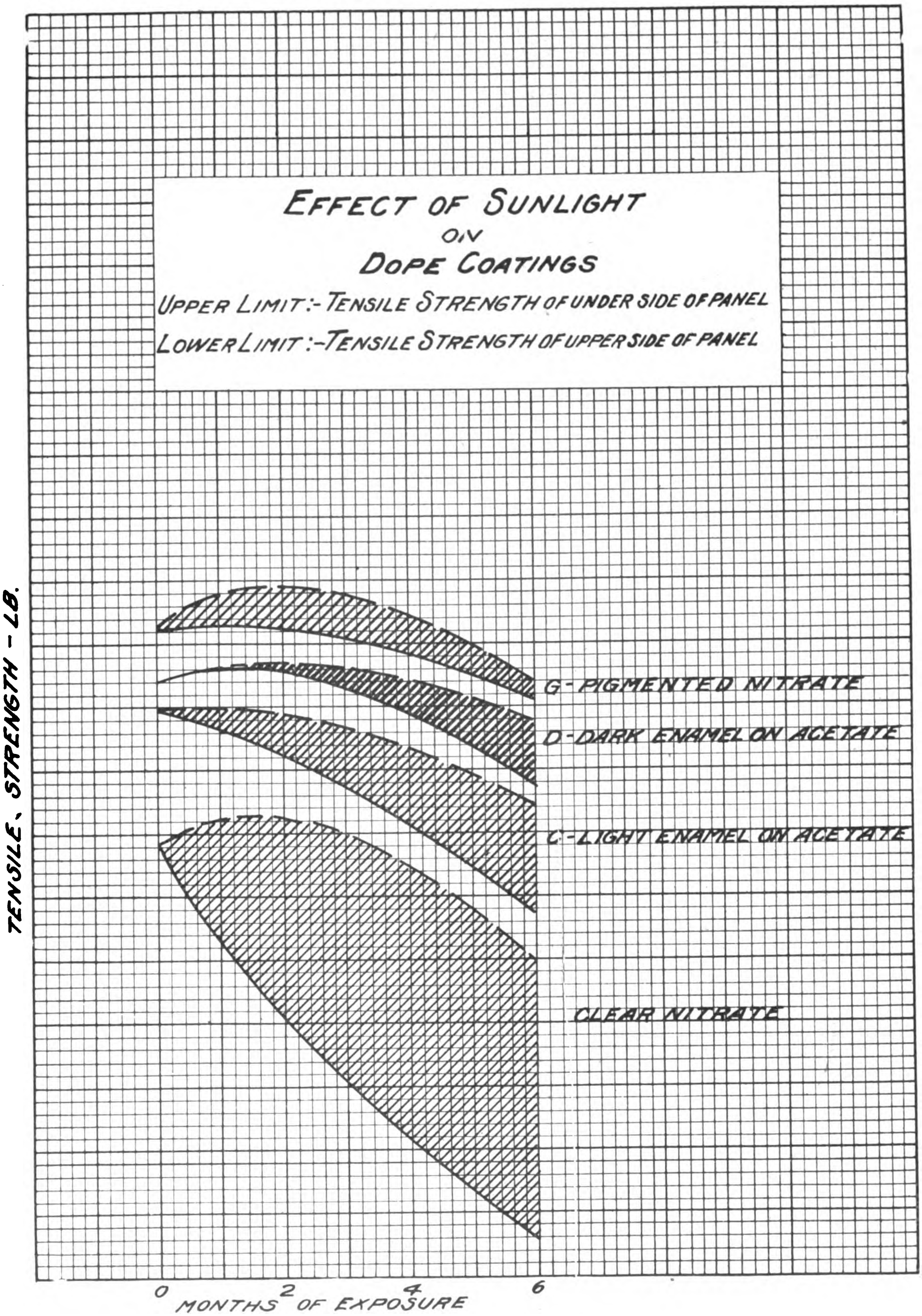

EFFECT OF SUNLIGHT
ON
DOPE COATINGS
UPPER LIMIT:- TENSILE STRENGTH OF UNDER SIDE OF PANEL
LOWER LIMIT:- TENSILE STRENGTH OF UPPER SIDE OF PANEL
G-PIGMENTED NITRATE
D-DARK ENAMEL ON ACETATE
C-LIGHT ENAMEL ON ACETATE
CLEAR NITRATE
TENSILE, STRENGTH - LB.
0
2
4
6
MONTHS OF EXPOSURE

FIG. 4.

File D 10.1/80 McCOOK FIELD REPORT, SERIAL No. 1964

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV December 1, 1922 No. 385

INVESTIGATION OF COPPER-SILICON-ALUMINUM ALLOYS WITH AND WITHOUT MANGANESE

(MATERIAL SECTION REPORT No. 178)

▽

Prepared by E. H. Dix, jr., and A. J. Lyon
Engineering Division, Air Service
McCook Field, Dayton, Ohio
June 30, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INVESTIGATION OF COPPER-SILICON-ALUMINUM ALLOYS WITH AND WITHOUT MANGANESE.

PURPOSE.

To investigate the mechanical and physical properties and casting qualities of the alloys of copper, silicon, and aluminum, containing from 0 to 9 per cent silicon and from 0 to 6 per cent copper, and to note the effect of the addition of 1 per cent of manganese to certain of these alloys.

CONCLUSIONS.

1. Alloys of aluminum containing 3 to 5 per cent of silicon in combination with copper within the same limits are suitable for the same general casting purposes as alloy No. 1—copper 8 per cent, aluminum 92 per cent—Air Service Specification 11023. The fundamental value of the alloys containing silicon, and their advantage over aluminum alloy No. 1, lies in their relative freedom from casting defects, such as cracks, due to solidification shrinkage, hot shortness, draws, and porosity.

2. One per cent of added manganese slightly raises the strength at high temperature but impairs the casting properties. Its use in the copper-silicon-aluminum alloys is not justified.

3. The mechanical properties of the copper-silicon alloys are about the same as those of aluminum alloy No.1. The ductility is slightly better and the solidification shrinkage and specific gravity slightly less. The machining properties are inferior to alloy No. 1. The best alloys of this series, with regard to machinability, are those with copper corresponding to the upper limits, and silicon to the lower limits of the compositions stated above. Since the silicon decreases the elongation at a slower rate than the copper, an alloy of 3 per cent copper, 4 per cent silicon, and balance aluminum has been chosen for general casting purposes.

4. The following metallographic constituents have been observed in specimens of this series of alloys:

(*a*) $CuAl_2$ aluminum eutectic.

(*b*) Silicon-aluminum eutectic.

(*c*) Needles, generally supposed to be $FeAl_3$.

(*d*) A probable compound of iron and silicon and perhaps aluminum, which resembles in color the characteristic needles of what has been called $FeAl_3$.

(*e*) A constituent which usually appears as blue-gray cubes.

(*f*) With the addition of manganese, a constituent of a peculiar swastika form appears which was not identified.

MATERIAL.

Grade 2 (Specification 11011-A), aluminum ingot (Melt 920), of the following analysis—silicon 0.99, copper 0.32, iron 0.51, manganese nil, aluminum (by difference) 98.18—was used throughout this investigation. It will be noted that silicon is the only impurity in excess. A silicon-aluminum hardener (Melt 958) was purchased from the Electro Metallurgical Corporation, Niagara Falls, N. Y., and had the following analysis: Silicon 60.51, copper 0.30, iron 1.22, aluminum (by difference) 37.97. The 50-50 copper-aluminum hardener (Melt 1006) was made in this foundry and had the following chemical analysis: Copper 49.55, silicon 0.17, iron 0.21, aluminum (by difference) 50.07. The manganese (94–95 per cent pure) was obtained from the Goldschmidt Thermit Corporation and is supposed to be practically free from iron and carbon. No analysis was made.

PROCEDURE.

MANUFACTURE OF HARDENERS.

The manganese was introduced in the form of a 90–10 aluminum-manganese hardener. A 10-pound melt of this hardener was made by melting 1 pound of manganese and 4½ pounds of aluminum ingot together in the small Ajax electric induction furnace. It was necessary to heat this charge to 1,900° F. before the manganese and aluminum would alloy. The balance of the aluminum ingot was then added, and after thorough stirring poured at a temperature of 1,600° F. into cast-iron molds. The analysis obtained on a sample from this melt (Melt 1047) follows: Copper 0.17, silicon 0.40, iron 0.54, manganese 10.10, aluminum by difference.

A 50–50 copper-aluminum hardener was used to introduce the copper in the alloys. This was made according to the usual foundry procedure; the copper and half of the aluminum were melted separately and the molten aluminum poured into the copper, the balance of the aluminum being added cold to act as a chill.

METHOD OF MAKING ALLOYS.

Fifteen alloys containing different combinations of silicon and copper, with and without manganese, were made in melts of 40 pounds each. The required percentages of hardeners and aluminum ingot were all charged together in a No. 40 plumbago crucible and melted in an oil-fired furnace. Temperature measurements were made by a bare chromel-alumel thermocouple (No. 8 gauge), immersed in the molten metal, and used in conjunction with a Hoskins high-resistance millivoltmeter. The melts were heated to, but not above, 1,400° F. in order to allow thorough alloying. A uniform pouring temperature of 1,300° F. was maintained. The time in the furnace averaged about 1 hour.

The following test specimens were poured in green sand from each melt:

Six molds, pattern TB–1, tension tests "as cast" and at high temperature.

Two molds, pattern TB–1A, tension tests "machined."

Two molds, pattern TB–4, coefficient of expansion tests.

One mold, pattern TB–6, impact tests.

Three molds, pattern PC–2, porosity tests.

Three shrinkage bars (see fig. 1).

One mold, hot shortness bar (see fig. 2).

Modulus of elasticity specimens were cast from remelts of the gates and risers of the above as follows:

One mold, pattern TB–13, "as cast" specimen.

One mold, pattern TB–14, "machined" specimen.

PHYSICAL TESTING.

The following tests were made by the Physical Testing Branch:

Five tension tests, "as cast," at normal temperatures, pulled in wedge grips.

Five tension tests, "as cast," at 300° F., pulled in self-aligning adapters.

Five tension tests, "as cast," at 600° F., pulled in self-aligning adapters.

Three tension tests, "as cast," after 30 days' aging.

Five tension tests, "as cast," after nine months' aging.[1]

Six tension tests, on "machined" specimens, at normal temperature.

Twelve Charpy impact tests on standard 10 mm. square specimens with 2 mm. diameter drilled notch 5 mm. deep.

Three shrinkage test measurements.

Three porosity tests.

One hot shortness test.

The last four tests are the only ones which require a description in this report, all of the others being performed according to standard methods. The shrinkage test bar is shown in Figure 1. This bar is cast in green sand between graphite plates set exactly 12 inches apart by a master bar. The final length of the bar, after cooling, is measured by a micrometer and the difference between this length and the length of a master bar taken as the shrinkage in inches per foot for the alloy.

The porosity tests were made in accordance with the procedure described in Material Section Report No. 160, McCook Field Serial No. 1882.

Figure 2 shows the apparatus devised for testing the hot shortness of this series of alloys. By casting the test bar around two fixed lugs, 12 inches apart, the normal shrinkage of the metal is prevented.

The modulus of elasticity tests were made in the usual way, and the deformations were taken by a Ewing extensometer.

The coefficient of expansion and thermal conductivity determinations were made by the Bureau of Standards, the former by their standard method and the latter by a method described by them in the following:

"METHOD OF TEST.

"The specimens were in the form of short cylinders, 1½ inches in diameter and about three-fourths inch long. The ends were ground flat to a few thousandths of a millimeter and the specimen placed between two longer brass cylinders of the same diameter, in such a way that the axes of the three cylinders were in the same straight line. Good thermal contact between the brass and the test material was obtained by wetting the contact surfaces with a dilute solution of glycerin. One end of this system of cylinders was heated electrically and the other end cooled with water in order to produce a temperature gradient along the axis. Since the heat loss from the convex surface of the cylinders is small in comparison with the total heat flow, practically the same amount of heat flows through both brass and specimen, and the ratio of the thermal conductivities of the two materials will be equal to the inverse ratio of the temperature gradients in each. The temperature gradient in the brass on both the hot and cold side of the specimen was measured by means of thermocouples inserted in small holes regularly spaced along the bars, and the temperature of each end of the test cylinder was assumed to be the same as that of the brass in contact with it. Separate experiments had shown that this was the case to about 0.1° C., the limit of precision of measurement with the apparatus used.

"All the samples were compared in this way with the brass, and the latter was in turn compared with several pure metals of known conductivity as a check on the method, and as a means of giving absolute values of thermal conductivity to the various alloys."

RESULTS.

The results of the mechanical properties of these alloys are summarized in Table 1. The detailed results are filed in both the Material Section general file and the Metals Branch file and may be referred to through the melt numbers. Table 2 gives the results of coefficient of expansion tests (Bureau of Standards Report No. Twe 32754). The thermal conductivity results (Bureau of Standards Report No. Tth 33517) are given in Table 3. Table 4 contains the observations made by the machine shop when the test bars of these alloys were machined. Table 5 gives the results of the porosity tests. Table 6 gives the results of the tension tests made on the hot shortness bars. Table 7 gives the averaged results of the Charpy impact tests.

These results are further shown graphically as follows:

Figures 3 to 7 show the effect of composition on tensile strength, elongation, impact, hardness, shrinkage, expansion, and specific gravity.

Figures 8 to 12 show the stress deformation characteristics of these alloys.

Figures 13 and 14 show the effect of copper with and without manganese on the tensile strength and elongation of silicon-aluminum alloys at elevated temperatures.

The metallographic structure of this series is illustrated by 18 micrographs as follows:

Figures 15 and 16 show an average and segregated area of the aluminum ingot used.

Figures 17 to 19, inclusive, show the effects of 3, 6, and 9 per cent silicon on commercially pure ingot.

Figures 20 and 21 show the effect of 4 and 6 per cent copper with 3 per cent silicon on aluminum.

Figure 22 shows the effect of manganese with 3 per cent silicon, 2 per cent copper, on aluminum.

[1] Except Melts 1021 and 1071, which had only 3 and 4 specimens, respectively.

DISCUSSION OF RESULTS.

TENSION TESTS ON "AS CAST" SPECIMENS.

These tests, which were made within 24 hours after casting, show that the addition of silicon up to the limit of these experiments (9 per cent) increases the tensile strength at the expense of the elongation, and the effect of the added silicon is more pronounced below 6 per cent than above. Copper, as is well known, has a similiar effect on the tensile strength and decreases the elongation more rapidly than the silicon, and therefore, due to the combined action of copper and silicon, it is necessary that the total of the two elements be less than 10 per cent. The best combinations of tensile strength and elongation have been obtained with copper and silicon between 3 and 5 per cent each. The alloy of 3 per cent copper and 4 per cent silicon has been used for considerable routine work and has been found to give a good combination of strength and elongation (tensile strength 21,000 pounds per square inch, elongation 2.5 per cent).

TENSION TESTS ON "MACHINED" SPECIMENS.

The tension tests on the machined specimens average about 850 pounds per square inch lower than those tested with the skin on, and the elongation is about the same.

AGING TESTS.

The results obtained on test bars tested 30 days after casting and 9 months after casting show that the aging effect on this series of alloys is negligible. There is only one melt which showed any notable difference, namely, Melt 1048, containing 6.39 per cent copper and 3.90 per cent silicon. This showed an increase in tensile strength in the 9 months' aging tests of about 4,000 pounds per square inch, with about the same elongation. This is, however, probably due to differences in test bars rather than any aging effect.

MODULUS OF ELASTICITY TESTS.

The average modulus of elasticity obtained from the bars "as cast" is 11,500,000 pounds per square inch. The complete stress deformation curves are included in the report. The proportional limit of the alloys, containing from 3 to 5 per cent each of copper and silicon, is about the same as the 8 per cent copper-aluminum alloy (about 6,000 pounds per square inch).

BRINELL AND SCLEROSCOPE HARDNESS TESTS.

The Brinell and scleroscope hardness is increased by the addition of either copper or silicon and also by the addition of both together. In general the hardness values for these alloys are slightly lower than the standard 8 per cent copper-aluminum alloy.

CHARPY IMPACT TESTS.

In the straight silicon-aluminum alloys the impact resistance is apparently reduced by the addition of silicon. In the alloys containing copper the effect of silicon is erratic. The impact resistance seems to be increased by the addition of copper to the silicon-aluminum alloys.

PATTERN SHRINKAGE.

The pattern shrinkage of this whole series of alloys is slightly lower than that of the standard 8 per cent copper-aluminum alloy, the latter having a shrinkage of 0.187 inch per foot as determined in a similar manner.

COEFFICIENT OF EXPANSION.

Coefficient of expansion results show that the expansion is only slightly influenced by the addition of either copper or silicon and that the expansion of this whole series is very close to that of the standard 8 per cent copper-aluminum alloy.

THERMAL CONDUCTIVITY TESTS.

Thermal conductivity tests as made by the Bureau of Standards indicate some small variations in this series, but these variations can not be attributed to the varying percentages of copper and silicon. The values obtained are similar to the value obtained for the 8 per cent copper-aluminum alloy.

MACHINING QUALITIES.

The straight silicon-aluminum alloys machine very poorly. The metal tears in much the same manner as pure aluminum and in addition the particles of silicon shown in Figures 17 to 19 appear to dull the tool very rapidly. The addition of copper improves the machining qualities due to the $CuAl_2$ network shown in Figure 20–A. The alloy of 3 per cent copper and 4 per cent silicon machines fairly well, although not as well as the standard 8 per cent copper-aluminum alloy.

POROSITY TESTS.

This whole series of alloys gave very good results in the porosity tests. The straight silicon-aluminum alloys were exceptionally good.

HOT SHORTNESS TESTS.

The most remarkable feature of this whole series of alloys is their ability to be cast around nonyielding cores without cracking. Only one composition (Melt 1069, Cu 6.29, Si 9.00, Fe 0.66) of this series of alloys cracked under the very severe hot shortness test which has been devised. Further, when these bars were tested, they showed a strength slightly greater than the average for the "as cast" test bars and an elongation slightly lower, as though they had received a certain amount of cold working.

METALLOGRAPHIC STUDY.

The metallography of this series of alloys can be best explained by first considering the structure of the aluminum ingot from which all of the alloys were prepared. A transverse section of the three-fourths-inch diameter end of a specimen cast in green sand according to pattern TB–1 was examined in detail. The constituents found are illustrated in Figures 15 and 16. At 100 X the aluminum solid solution matrix was found to include a network of impurities as shown in Figure 15A. It was noted that near the pipe at the center of the test bar the impurities had segregated in large amounts as illustrated by Figure 16A. Upon examination at 500 X the individual constituents composing the network were distinguishable as shown in Figures 15B and 16B, but these are more easily differentiated

at 1,000 X, as shown by Figures 15C and 16C. The particles appearing black in Figure 15C appear a dark purple under visual examination and the needles which appear in half-tone were a light-gray under visual examination. Figures 16B and 16C show that the network in the segregated area has a distinctly different appearance. The particle shown in Figure 16C appeared the same shade as the needles shown in Figure 15C. Very little of the dark purple constituent was found in this segregated area; the black areas in the particle of Figure 16C are crevices.

The dark purple particles were found to increase with the addition of silicon, and to assume a eutectic network, as shown in Figures 17, 18, and 19. With 3 per cent added silicon, the eutectic particles are very fine, as shown in Figures 17A and 17B. The needles shown in these figures were apparently the same constituent observed in the form of needles in the original ingot. As the per cent of added silicon was increased, some of the areas of eutectic particles became much coarser, as shown in Figures 18A and 18B. It is therefore safe to conclude that the dark purple particles observed in the original ingot and the eutectic noted above are particles of pure silicon, since it is known (references 1 and 2) that silicon does not form a compound with the aluminum. The needles have generally been conceded to be the compound $FeAl_3$, but iron is also thought to form a compound with silicon, containing perhaps some aluminum, which has been called the "X constituent" by other experimenters (references 3 and 4). It seems reasonable to conclude, however, that if iron forms two separate constituents, the crystal habits of these constituents are probably different, so that the $FeAl_3$ may always form needles, whereas the other compound may take an entirely different form or forms. Considerable attention was paid to this point, but it seemed to be impossible to differentiate between the needles and several other constituents by any means at present available. A constituent having the same color but a dendritic formation is shown in Figures 21A and 21B, and further with the addition of manganese a very similar constituent was found to occur in a characteristic swastika form, as shown in Figures 22A and 22B. Thus, it was impossible to distinguish by color or etching characteristics between the needles in Figure 15C or the particles in Figure 16C or the dendritic structure in Figure 21B or the swastika form in Figure 22B. It is recognized that a constituent may occur in different forms due to many influences, and as a result of a prolonged examination of these specimens at 1,000 X, this grayish constituent must be recognized as occurring in four distinct forms probably representing three different constituents—the compound $FeAl_3$, the "X" constituent, and a constituent due to the presence of manganese.

In all of these alloys bluish-gray cubes, as illustrated in Figures 19A and 19B, were recognized. These seem to be more numerous in the higher silicon alloys and may perhaps be primary silicon crystals or particles due to some unknown impurity in the silicon hardener.

In the alloys containing copper the $CuAl_2$ compound was easily distinguished due to previous work on these alloys. In the unetched specimen it appeared a clear white with a pink tinge and was readily distinguished from the silicon or the iron constituents. It was also identified by the method of etching described by Hanson (reference 5), which consists in immersing the specimen in 20 per cent aqueous HNO_3 at 70° C. followed by a quench in cold water. This colors the $CuAl_2$ from a chocolate to black, depending upon the time of immersion in the acid. Figures 20A and 20B show the structure of the alloy containing 4 per cent copper and 3 per cent silicon. In Figure 20B silicon appears dark and the $CuAl_2$ particles light. In addition to these two constituents, there will be noted particles in half tone which appear as needles and elongated globules. This constituent under visual examination has the characteristic gray color which distinguishes the iron compound, but it is not possible to say whether it is $FeAl_3$ or the "X constituent."

The segregation shown in Figures 15 and 16 gives evidence of the value of metallography as a check on chemical analysis, for a sample taken from the segregated area of Figure 16 would give a very erroneous idea of the average composition of the specimen.

REFERENCES.

(1) C. E. Roberts, "The Alloys of Aluminum and Silicon," Transactions, Chemical Society (London), vol. 105, pp. 1383–1386.

(2) W. Fraenkel, "Silicon-Aluminum Alloys," Zeit. Anorg. Chem., vol. 58, pp. 154–158; Abstracts, Chem. Zentralbl., vol. 11, p. 143.

(3) The Eleventh Report of the Alloys Research Committee to Institute Mechanical Engineers (British).

(4) P. D. Merica, R. G. Waltenberg, and J. R. Freeman, jr., "The Constitution and Metallography of Aluminum and Its Light Alloys with Copper and with Magnesium," Scientific Paper No. 337, U. S. Bureau of Standards, 1919.

(5) D. Hanson and S. L. Archbutt, "The Micrography of Aluminum and Its Alloys," Journal of the Institute of Metals, Vol. XXI, No. 1, 1919.

TABLE 1.—*Summary of results.*

•	Yield point, pounds per square inch.	Tensile strength, pounds per square inch.	Elongation, per cent in 2 inches.	Modulus of elasticity X 10^6.	Brinell, 500 kg.	Scleroscope.	Charpy impact.	Specific gravity.	Shrinkage, inches per foot.
				Melt 1010—Cu 0.41, Si 4.12, Fe 0.59.					
"As cast"		18,120	4.9	....	35.2	8.5	....	2.65	0.164
"Machined"	10,500	17,180	5.3	....	33.8	7.2	2.13	....	....
30 days' aging		19,520	5.3	....	34.8	9.7	....	....	....
9 months' aging		19,260	4.0	....	34.5	....	....	....	....
Modulus spec.:									
"As cast"		17,350	.75	12.3	(Melt 1089	Elongation in 8 inches.)			
"Machined"		15,520	3.50	11.4					

TABLE 1.—*Summary of results*—Continued.

	Yield point, pounds per square inch.	Tensile strength, pounds per square inch.	Elongation, per cent in 2 inches.	Modulus of elasticity, X 10⁶.	Brinell, 500 kg.	Sclero-scope.	Charpy impact.	Specific gravity.	Shrinkage, inches per foot.
Melt 1012—Cu 0.42, Si 6.20, Fe 0.90.									
"As cast"		19,800	4.2		36.7	9.3		2.63	0.161
"Machined"	15,830	18,680	4.2		36.3	8.1	2.07		
30 days' aging		21,520	4.2		38.0	11.0			
9 months' aging		19,800	4.25		35.0				
Modulus spec.:									
"As cast"		18,440	2.75	11.4	(Elongation in 8 inches.)				
"Machined"		17,020	2.5	10.5					
Melt 1016—Cu 0.34, Si 9.34, Fe 0.73.									
"As cast"		18,986	2.8		37.0	10.0		2.60	0.163
"Machined"	15,990	18,610	3.0		34.8	7.9	1.78		
30 days' aging		20,120	2.5		35.0	11.0			
9 months' aging		18,430	3.0		41.0				
Modulus spec.:									
"As cast"		19,470	2.25	12.3	(Elongation in 8 inches.)				
"Machined"		16,930	1.75	10.8					
Melt 1021—Cu 2.15, Si 2.66, Fe 0.62.									
"As cast"		20,260	3.5		42.4	9.4		2.70	0.171
"Machined"	16,680	20,180	3.17		44.8	8.9	2.50		
30 days' aging		22,050	3.3		39.0	11.0			
300° F.		20,070	3.5						
600° F.		10,640	12.0						
Modulus spec.:									
"As cast"		19,260	1.88	11.4	(Elongation in 8 inches.)				
"Machined"		18,140	1.62	10.6					
Melt 1025—Cu 2.32, Si 6.69, Fe 0.65.									
"As cast"		19,882	2.0		50.0	12.0		2.67	0.158
"Machined"	17,960	20,410	2.5		50.0	10.6	2.31		
30 days' aging		21,660	1.3		51.0	12.3			
300° F.		19,360	2.5						
600° F.		11,770	7.4						
Modulus spec.:									
"As cast"		22,230	1.62	11.4	(Elongation in 8 inches.)				
"Machined"		19,640	1.12	12.2					
Melt 1026—Cu 2.29, Si 9.58, Fe 0.71.									
"As cast"		21,610	1.5		55.4	12.4		2.63	0.159
"Machined"	18,390	22,150	2.3		51.3	10.7	2.53		
30 days' aging		22,150	2.2		47.0	16.0			
300° F.		20,800	2.0						
600° F.		10,530	4.5						
Modulus spec.:									
"As cast"		20,770	1.0	11.4	(Melt 1141—Elongation in 8 inches.)				
"Machined"		19,360	.75	11.4					
Melt 1036—Cu 4.25, Si 3.41, Fe 0.74.									
"As cast"		21,740	2.2		54.6	13.0		2.72	0.163
"Machined"		21,300	1.1		55.0	13.0	2.18		
30 days' aging		23,970	1.7		60.0	14.0			
9 months' aging		23,360	1.5		55.0				
Modulus spec.:									
"As cast"		19,870	.38	11.4	(Melt 1102—Elongation in 8 inches.)				
"Machined"		21,210	.75	11.8					
Melt 1042—Cu 4.17, Si 4.92, Fe 0.72.									
"As cast"		22,170	1.4		59.4	13.0		2.69	0.158
"Machined"	15,710	22,420	1.0		59.0	13.7	2.74	2.70	
30 days' aging		24,550	1.7		65.0	15.0		2.71	
300° F.		22,880	2.2						
600° F.		13,410	5.3						
Modulus spec.:									
"As cast"		22,190	.75	11.0	(Melt 1142—Elongation in 8 inches.)				
"Machined"		20,800	.62	11.4					

TABLE 1.—*Summary of results*—Continued.

	Yield point, pounds per square inch.	Tensile strength, pounds per square inch.	Elongation, per cent in 2 inches.	Modulus of elasticity, X 10^6.	Brinell, 500 kg.	Sclero-scope.	Charpy impact.	Specific gravity.	Shrinkage, inches per foot.
Melt 1044—Cu 4.26, Si 10.12, Fe 0.70.									
"As cast"		22,540	0.9		65.0	15.0		2.69	0.151
"Machined"	16,880	21,500	1.4		64.0	14.3	2.46	2.67	
30 days' aging		23,640	0.5		70.0	16.3		2.67	
9 months' aging		23,850	1.3		70.0				
Modulus spec.:									
"As cast"		18,420	.25	11.4	(Melt 1144—Elongation in 8 inches.)				
"Machined"		20,220	.88	12.3					
Melt 1048—Cu 6.39, Si 3.90, Fe 0.77.									
"As cast"		23,210	0.9		59	14		2.74	0.159
"Machined"	12,070	20,290	1.17		65	16	2.63	2.75	
30 days' aging		23,380	1.0		65	18		2.74	
9 months' aging		27,260	1.16		68				
Modulus spec.:									
"As cast"		21,370	0.62	11.2	(Melt 1166—Elongation in 8 inches.)				
"Machined"		20,080	0.6	10.7					
Melt 1065—Cu 6.39, Si 6.28, Fe 0.51.									
"As cast"		24,960	0.4		59	14		2.74	0.156
"Machined"	17,350	24,210	1.17		63.5	16	2.45	2.76	
30 days' aging		21,160	.5		71.3	15.6		2.75	
300° F		23,200	1.5						
600° F		13,850	2.8						
Modulus spec.:									
"As cast"		20,290	0.5	10.8	(Melt 1165—Elongation in 8 inches.)				
"Machined"		18,910	0.4	11.4					
Melt 1069—Cu 6.29, Si 9.00, Fe 0.66.									
"As cast"		24,170	1.0		56	17			0.150
"Machined"		20,145	1.25		66	15.6	2.61	2.73	
30 days' aging		24,990	1.3		74	16.7		2.72	
9 months' aging		25,020	1.0		80.0				
Modulus spec.:									
"As cast"		19,560	0.25	11.4	(Melt 1164—Elongation in 8 inches.)				
"Machined"		20,920	0.4	11.4					
Melt 1071—Cu 2.33, Si 3.86, Fe 0.65, Mn 0.87.									
"As cast"		22,010	2.5		40	10			0.175
"Machined"		20,675	2.25		49.5	11	2.41	2.67	
30 days' aging		22,580	3.5		54.7	11.3		2.69	
300° F		20,940	3.5						
600° F		11,760	8.3						
Modulus spec.:									
"As cast"		20,160	1.5	10.5	(Melt 1163—Elongation in 8 inches.)				
"Machined"		18,690	1.5	11.2					
Melt 1073—Cu 2.40, Si 9.97, Fe 0.63, Mn 0.67.									
"As cast"		22,570	1.4		47	16		2.65	0.153
"Machined"		20,480	1.5		46.5	11.2	2.42	2.62	
30 days' aging		20,980	1.5		56	13.3		2.63	
300° F		21,590	1.7						
600° F		11,890	4.6						
Modulus spec.:									
"As cast"		21,020	1.0	11.4	(Melt 1157—Elongation in 8 inches.)				
"Machined"		20,370	1.12	11.4					
Melt 1076—Cu 2.20, Si 9.56, Fe 0.97, Mn 0.71.									
"As cast"		22,190	1.5		42.6	17		2.64	0.153
"Machined"		20,270	2.0		49.5	12	2.35	2.62	
30 days' aging		22,440	2.0		57	14.7		2.64	
300° F		20,150	1.5						
600° F		12,510	3.9						
Modulus spec.:									
"As cast"		21,800	1.25	12.3	(Melt 1156—Elongation in 8 inches.)				
"Machined"		19,600	0.9	11.4					

TABLE 2.—*Coefficient of expansion.*

(Bureau of Standards Report—Twe 32754.)

Melt No.	Copper.	Silicon.	Manganese.	Average coefficients of expansion.[1] 20° to 100° C.	100° to 200° C.	200° to 300° C.	20° to 300° C.
1010	0.41	4.12	....	0.0000222	0.0000240	0.0000258	0.0000241
1012	.42	6.20	....	.0000217	.0000232	.0000251	.0000234
1016	.34	9.34	....	.0000211	.0000226	.0000247	.0000229
1021	2.15	2.66	....	.0000234	.0000243	.0000253	.0000244
1025	2.32	6.69	....	.0000207	.0000226	.0000244	.0000227
1026	2.29	9.58	....	.0000218	.0000236	.0000247	.0000235
1036	4.25	3.41	....	.0000224	.0000242	.0000254	.0000241
1042	4.17	4.92	....	.0000214	.0000234	(2)	....
				.0000215	.0000230	.0000246	.0000231
1044	4.26	10.12	....	.0000204	.0000223	.0000238	.0000223
1048	6.39	3.90	....	.0000218	.0000238	.0000247	.0000236
1065	6.39	6.28	....	.0000204	.0000220	.0000237	.0000221
1069	6.29	9.00	....	.0000206	.0000224	.0000231	.0000222
1071	2.33	3.86	0.87	.0000222	.0000243	.0000245	.0000238
1073	2.40	9.97	.67	.0000208	.0000222	.0000237	.0000223
1076	2.20	9.56	.71	.0000204	.0000224	.0000241	.0000224

[1] Before the thermal expansion tests, these samples were heated to 400° C. and then allowed to cool in furnace.
[2] Observation wire broke at about 300° C. The results obtained on a repeated heating are given in the next line.

TABLE 3.—*Thermal conductivity.*

(Bureau of Standards Report—Tth 33517.)

Melt No.	Copper.	Silicon.	Manganese.	Tin.	Conductivity.[1]	Jaeger and Diesselhorst values.
1395[2]	....	....	....	.....	0.40	....
1397	7.49	0.39	0.47	.....	.30	....
1400	9.95	.37	....	.....	.32	....
1325	2.15	2.66	....	.....	.29	....
1324	3.05	4.02	....	.....	.32	....
1394	4.17	4.92	....	.....	.30	....
1326	2.33	3.86	.87	.....	.28	....
1327	6.85	.39	....	0.88	.36	....
99.7% Al	....	....	....	.....	.52	0.48
Zinc	....	....	....	.....	....	.265
Tin	....	....	....	.....	.16	.153
Lead	....	....	....	.....	.085	.082

[1] Zinc used as standard—conductivity 0.265 calories sec.$^{-1}$ deg.$^{-1}$ cm.$^{-1}$.
[2] Aluminum 99+.

TABLE 4.—*Machining tests.*

(Cutting speed, 95 feet per minute; revolutions per minute, 250.)

Melt No.	Copper.	Silicon.	Manganese.	Roughing cut.	Finishing cut.
1010	0.41	4.12	....	Rough cutting (tears, brittle).	Hard to polish (scratches).
1012	.42	6.20	....	Rough cutting (tears).	Do.
1016	.34	9.34	....	Rough cutting (deep tool marks).	Do.
1021	2.15	2.66	....	Moderately soft...	Polishes better (tool marks).
1025	2.32	6.69	....	.....do...........	Polishes better (smooth cutting).
1026	2.29	9.58	....	.....do...........	Do.
1036	4.25	3.41	....	.....do...........	Do.
1042	4.17	4.92	....	.....do...........	Polishes better (scratches due to pinholes).
1044	4.26	10.12	....	Soft cutting.......	Polished easy, but scratches (due to pinholes).
1048	6.39	3.90	....	.....do...........	Do.
1065	6.39	6.28	....	.....do...........	Do.
1069	6.29	9.00	....	.....do...........	Do.
1071	2.33	3.86	0.87	.....do...........	Polishes easy.
1073	2.40	9.97	.67	.....do...........	Smooth cutting, polishes well.
1076	2.20	9.56	.71	.....do...........	Do.

TABLE 5.—*Porosity tests.*

Specimen No.	Porosity number (seconds for 1000 cc.). As cast.	Machined inside.	Machined all over.	Thickness after machining all over (inch). Walls.	Bottom.
1010–13	No leak.	No leak.	No leak.	0.095	0.107
1010–14	No leak.	9,480	6,900	.095	.092
1010–15	No leak.	No leak.	No leak.	.092	.104
1012–1	No leak.	No leak.	No leak.	.110	.107
1012–2	1,045	638	615	.095	.112
1012–3	No leak.	No leak.	No leak.	.105	.103
1016–1	13,680	No leak.	12,000	.100	.098
1016–2	Trace.	Trace.	No leak.	.100	.103
1016–3	Trace.	No leak.	180,000	.095	.119
1021–1	6,235	4,470	30,000	.095	.117
1021–2	389	5,233	4,250	.110	.097
1021–3	216	808	1,020	.100	.116
1025–1	Trace.	No leak.	30,000	.095	.105
1025–2	414	310	146	.090	.087
1025–3	772	4,310	30	.095	.064
1026–1	No leak.	Trace.	1,590	.100	.088
1026–2	Trace.	6,470	120,000	.110	.085
1026–3	7,962	Trace.	60,000	.115	.104
1036–1	152	182	248	.088	.112
1036–2	No leak.	No leak.	No leak.	.095	.104
1036–3	No leak.	Trace.	60,000	.095	.091
1042–1	1,420	No leak.	6,000	.100	.115
1042–2	275	132	440	.090	.098
1042–3	No leak.	No leak.	No leak.	.095	.098
1044–1	No leak.	No leak.	425	.100	.107
1044–2	25,500	No leak.	6,000	.090	.128
1044–3	585	572	840	.100	.111
1048–1	No leak.	No leak.	930	.105	.105
1048–2	4,625	18,150	20,000	.110	.105
1048–3	2,530	233	188	.095	.086
1065–1	No leak.	120,000	No leak.	.100	.128
1065–2	No leak.	5,700	6,000	.090	.098
1065–3	2,965	2,015	386	.090	.095
1069–1	No leak.	5,880	20,000	.072	.108
1069–2	60,000	120,000	2,600	.110	.103
1069–3	No leak.	60,000	30,000	.080	.118
1071–1	No leak.	No leak.	No leak.	.105	.118
1071–2	No leak.	No leak.	No leak.	.095	.097
1071–3	No leak.	No leak.	No leak.	.090	.115
1073–1	706	750	120	.090	.103
1073–2	120,000	5,100	600,000	.085	.096
1073–3	No leak.	60,000	1,230	.095	.061
1076–1	No leak.	No leak.	1,360	.075	.125
1076–2	610	350	305	.085	.096
1076–3	No leak.	20,000	6,000	.088	.108

TABLE 6.—*Tension tests on hot shortness bars.*

Melt No.	Tensile strength, pounds per square inch.	Elongation, in 2 inch, per cent.	Brinell, 500 kg.	Scleroscope.
1010	18,140	3.5	25.7	[1] 12
1012	20,970	4.0	36	8
1016	19,560	2.0	40	11
1021	17,850	....	42	11.5
1025	21,940	2.0	47	12
1026	20,690	1.25	48	13
1036	23,410	2.0	50	12
1042	24,210	1.0	54	14
1044	24,440	0.5	50	15
1048	24,570	0.5	49	14
1065	24,960	2.0	59	14
1071	21,750	1.5	37.6	11
1073	24,100	1.0	53	16
1076	22,180	1.5	50	17

[1] Melt 1089.

Note: Test bar from Melt 1069 cracked in mold.

TABLE 7.—*Charpy impact results (foot-pound).*

Melt No.	Bar number.[1] A	B	C	D	Average.
1010	2.14	2.14	2.18	2.08	2.14
1012	2.08	2.13	2.01	2.08	2.07
1016	1.91	1.84	1.61	1.76	1.78
1021	2.43	2.76	2.37	2.45	2.50
1025	2.40	2.23	2.23	2.39	2.31
1026	2.94	2.05	2.39	2.73	2.53
1036	1.92	2.13	2.07	2.39	2.12
1042	2.77	2.67	2.71	2.83	2.74
1044	2.42	2.52	2.39	2.54	2.46
1048	2.54	2.42	2.77	2.71	2.63
1065	2.40	2.41	2.24	2.76	2.45
1069	2.73	2.58	2.47	2.65	2.61
1071	2.45	2.40	2.26	2.53	2.41
1073	2.51	2.25	2.16	2.75	2.42
1076	2.16	2.13	2.58	2.54	2.35

[1] The result for each bar is average of three specimens.

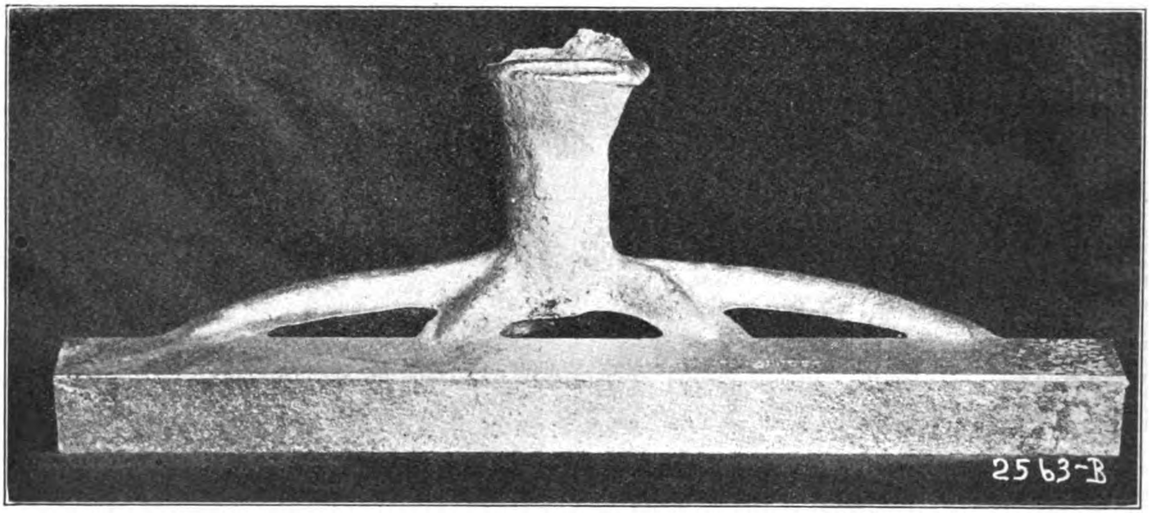


FIG. 1.—Method of casting shrinkage bars.

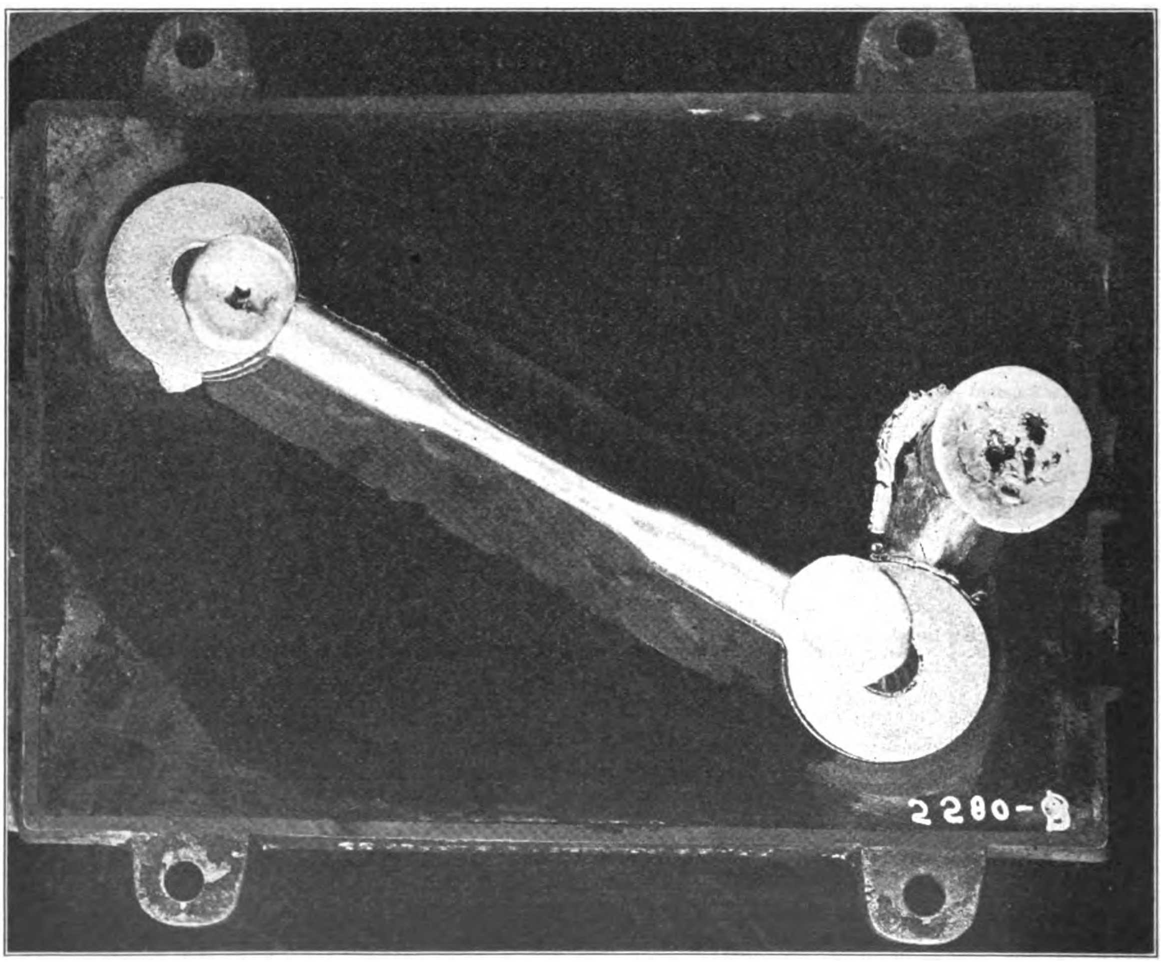


FIG. 2.—Hot shortness test.

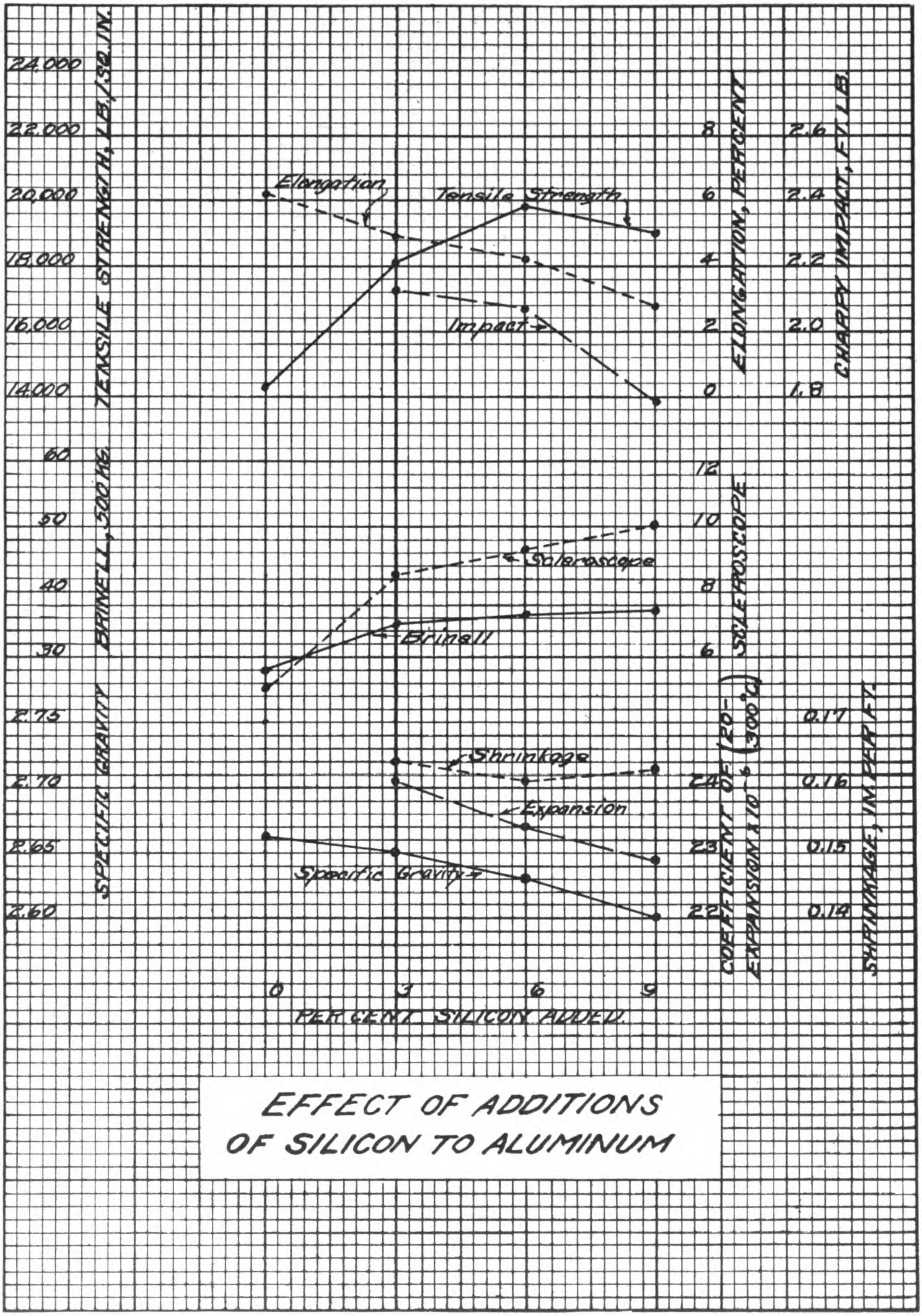

EFFECT OF ADDITIONS
OF SILICON TO ALUMINUM
TENSILE STRENGTH, LB./SQ.IN.
BRINELL, 500 KG.
SPECIFIC GRAVITY
ELONGATION, PERCENT
CHARPY IMPACT, FT. LB.
SCLEROSCOPE
COEFFICIENT OF (20-300°C) EXPANSION X 10^-6
SHRINKAGE, IN. PER FT.
PER CENT SILICON ADDED.
Elongation
Tensile Strength
Impact
Scleroscope
Brinell
Shrinkage
Expansion
Specific Gravity

FIG. 3.

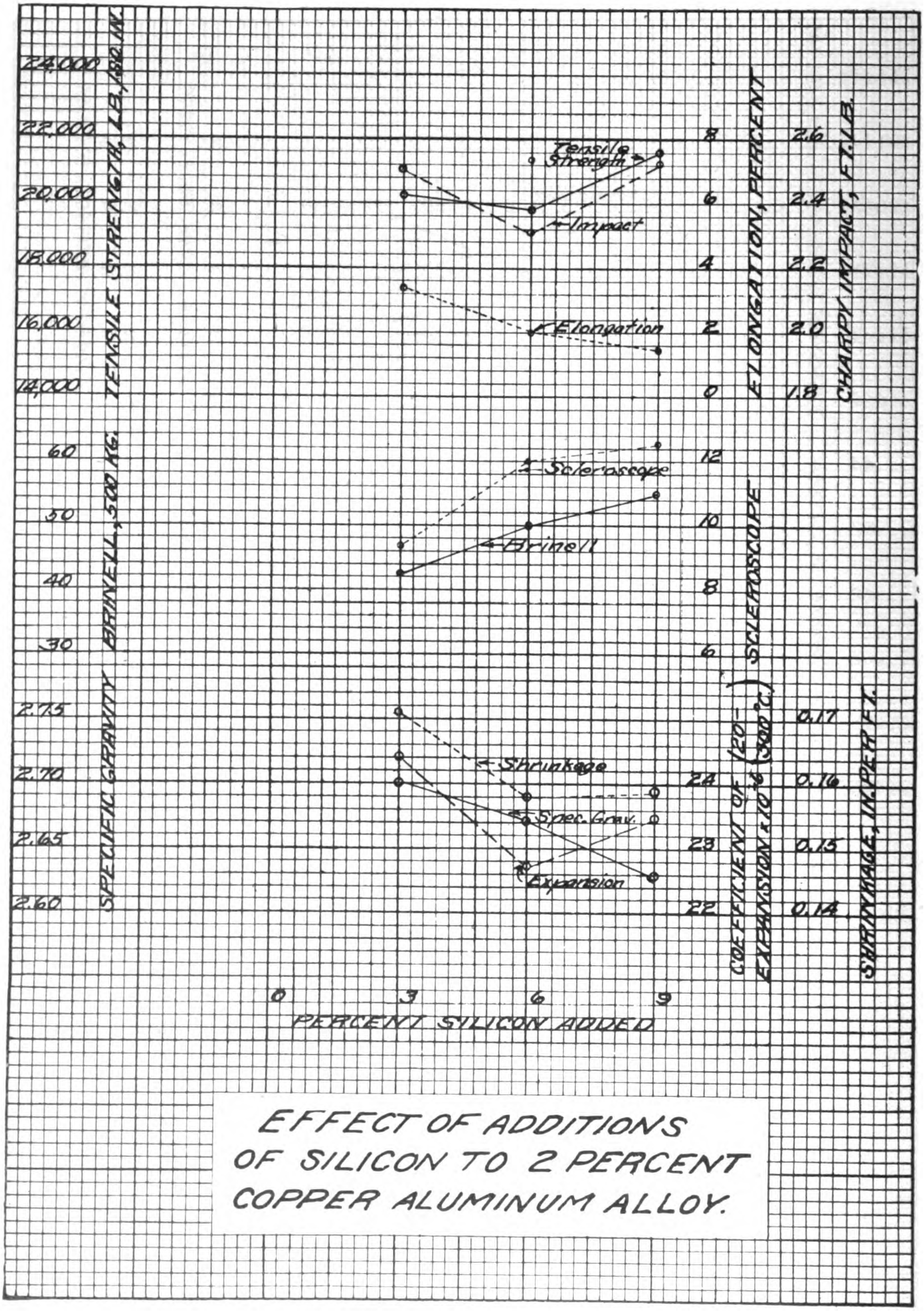

24,000
22,000
20,000
18,000
16,000
14,000
60
50
40
30
2.75
2.70
2.65
2.60
SPECIFIC GRAVITY BRINELL, 500 KG. TENSILE STRENGTH, LB./SQ.IN.
Tensile Strength
Impact
Elongation
Scleroscope
Brinell
Shrinkage
Spec. Grav.
Expansion
0
3
6
9
PERCENT SILICON ADDED
8
6
4
2
0
12
10
8
6
24
23
22
2.6
2.4
2.2
2.0
1.8
0.17
0.16
0.15
0.14
ELONGATION, PERCENT
SCLEROSCOPE
COEFFICIENT OF EXPANSION × 10⁻⁶ (20°–300° C.)
CHARPY IMPACT, FT. LB.
SHRINKAGE, IN. PER FT.
EFFECT OF ADDITIONS OF SILICON TO 2 PERCENT COPPER ALUMINUM ALLOY.

Fig. 4.

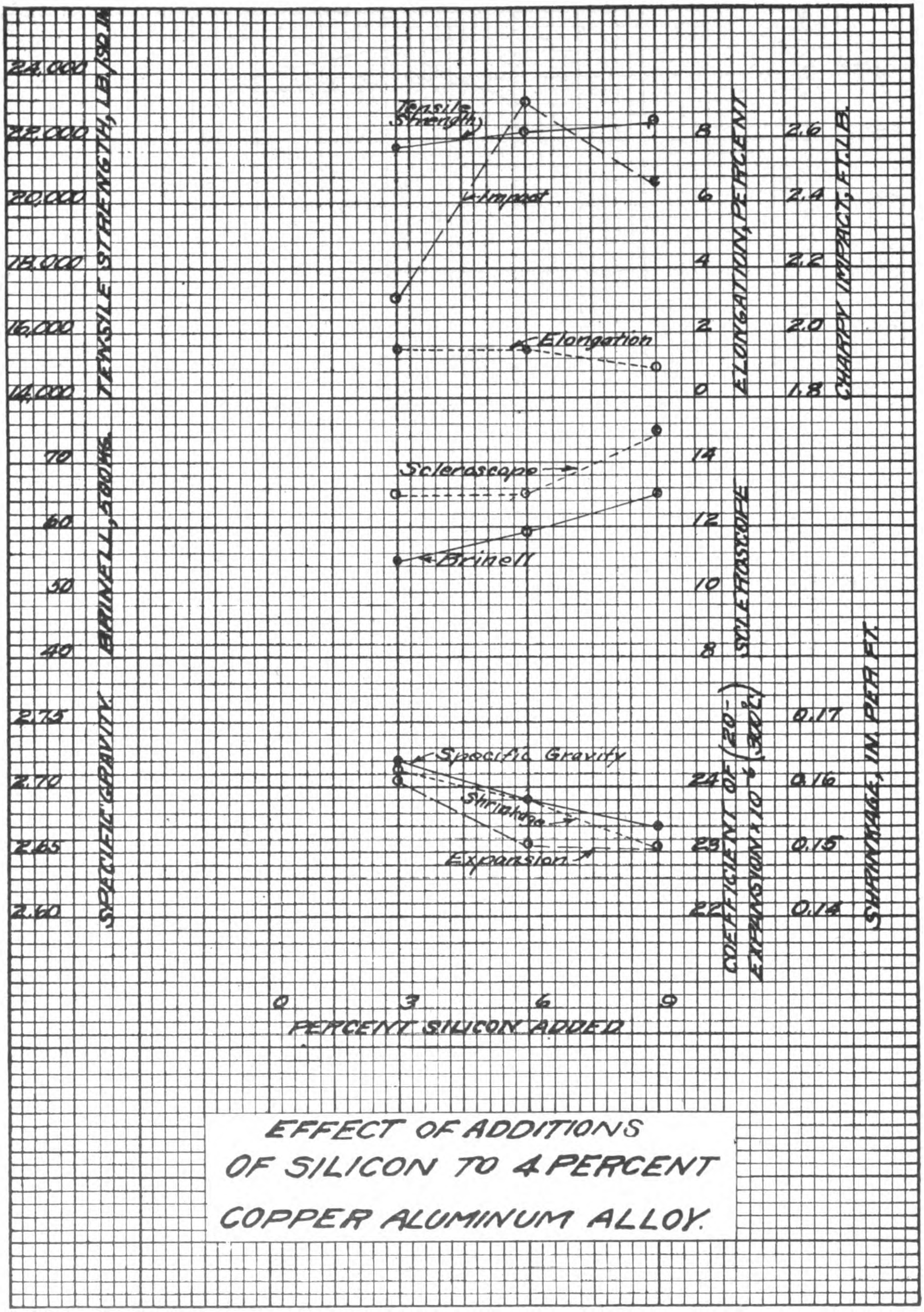

TENSILE STRENGTH, LB./SQ.IN.
24,000
22,000
20,000
18,000
16,000
14,000
BRINELL, 500 KG.
70
60
50
40
SPECIFIC GRAVITY.
2.75
2.70
2.65
2.60
Tensile Strength
Impact
Elongation
Scleroscope
Brinell
Specific Gravity
Shrinkage
Expansion
ELONGATION, PERCENT
8
6
4
2
0
CHARPY IMPACT, FT.LB.
2.6
2.4
2.2
2.0
1.8
SCLEROSCOPE
14
12
10
8
COEFFICIENT OF EXPANSION × 10⁻⁶ (20-300°C.)
24
23
22
SHRINKAGE, IN. PER FT.
0.17
0.16
0.15
0.14
0
3
6
9
PERCENT SILICON ADDED
EFFECT OF ADDITIONS OF SILICON TO 4 PERCENT COPPER ALUMINUM ALLOY.

Fig. 5.

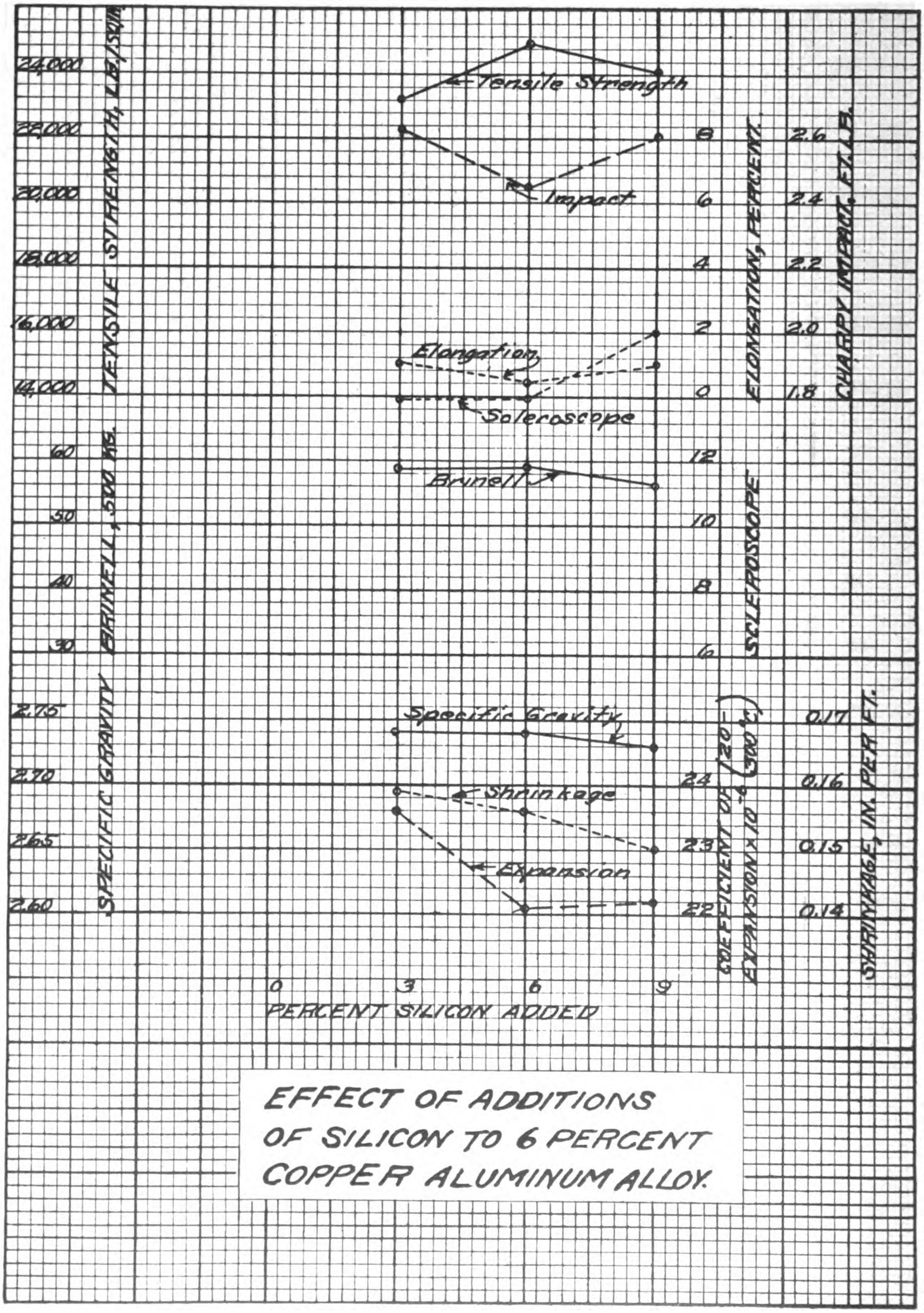

Tensile Strength
Impact
Elongation
Soleroscope
Brinell
Specific Gravity
Shrinkage
Expansion
SPECIFIC GRAVITY BRINELL, 500 KG. TENSILE STRENGTH, LB./SQ.IN.
ELONGATION, PERCENT
SCLEROSCOPE
CHARPY IMPACT, FT. LB.
COEFFICIENT OF (20-300°C) EXPANSION × 10⁻⁶
SHRINKAGE, IN. PER FT.
PERCENT SILICON ADDED
0 3 6 9
EFFECT OF ADDITIONS OF SILICON TO 6 PERCENT COPPER ALUMINUM ALLOY.

FIG. 6.

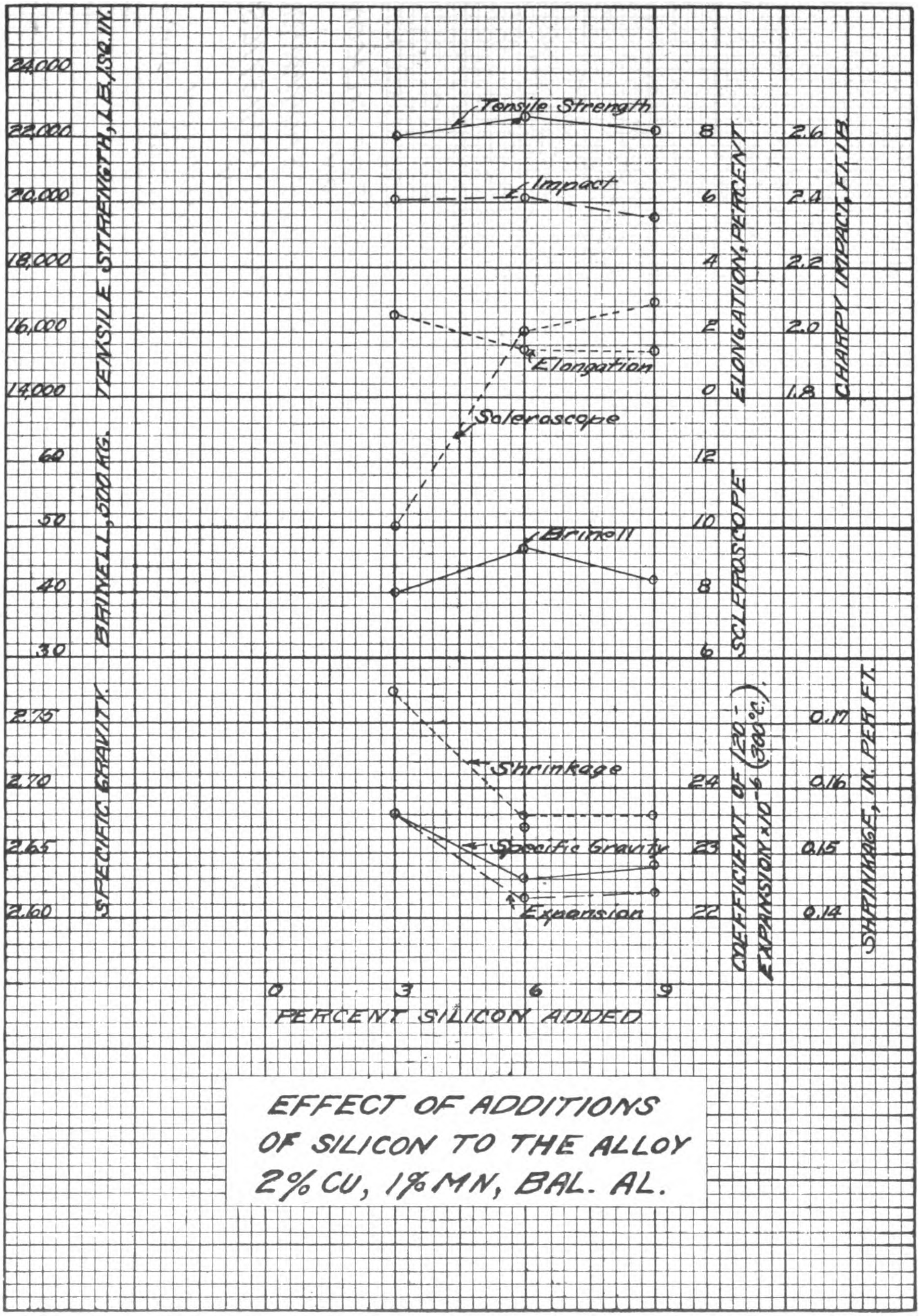

Tensile Strength
Impact
Elongation
Scleroscope
Brinell
Shrinkage
Specific Gravity
Expansion
SPECIFIC GRAVITY. BRINELL, 500 KG. TENSILE STRENGTH, LB./SQ.IN.
ELONGATION, PERCENT
CHARPY IMPACT, FT. LB.
SCLEROSCOPE
COEFFICIENT OF EXPANSION ×10⁻⁶ (20°-300°C.)
SHRINKAGE, IN. PER FT.
PERCENT SILICON ADDED
EFFECT OF ADDITIONS
OF SILICON TO THE ALLOY
2% CU, 1% MN, BAL. AL.

FIG. 7.

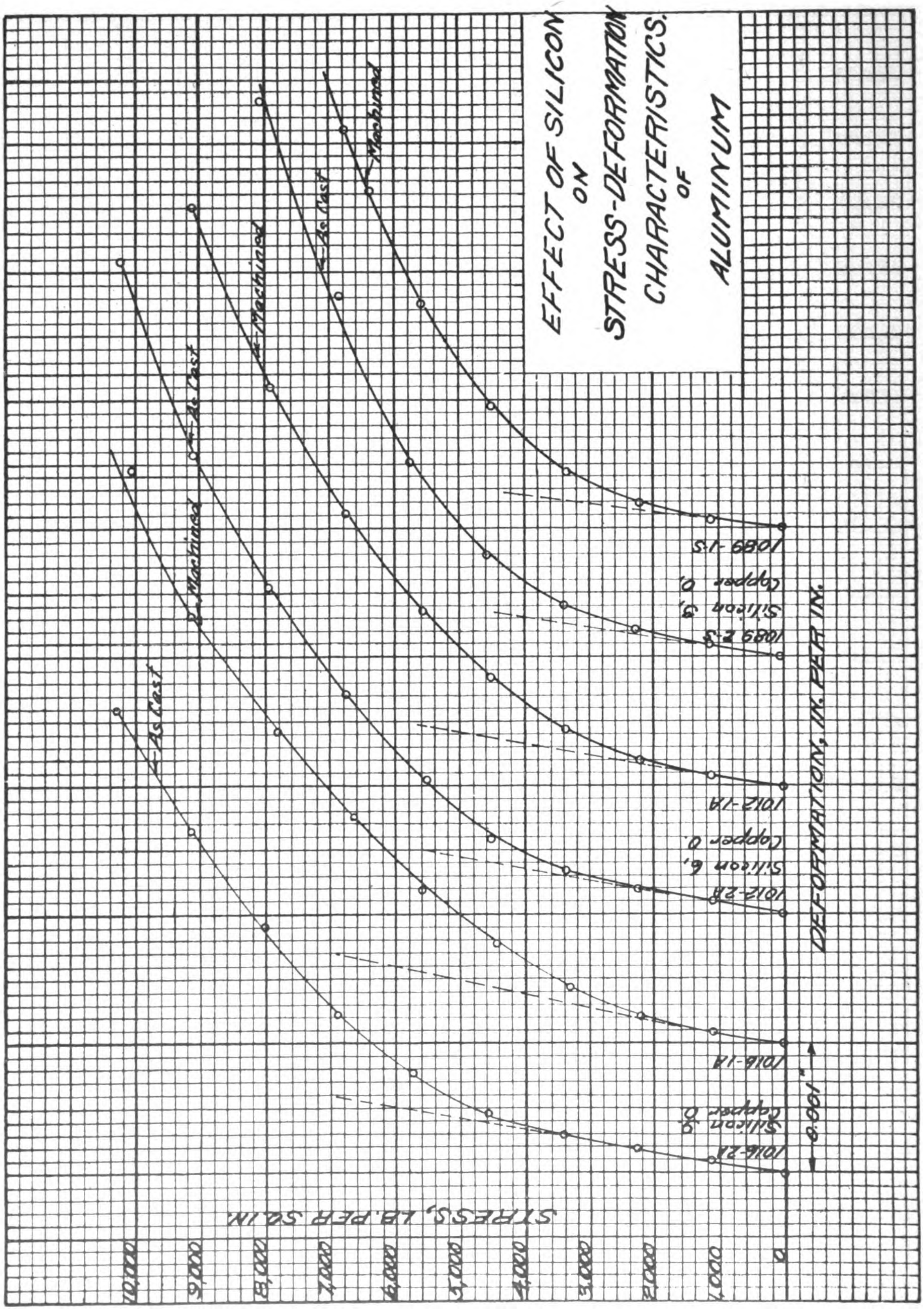

EFFECT OF SILICON ON STRESS-DEFORMATION CHARACTERISTICS OF ALUMINUM
STRESS, LB. PER SQ. IN.
DEFORMATION, IN. PER IN.
0.001"
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
1089-1S
Silicon 3, Copper 0.
1089-2S
1012-1A
Silicon 6, Copper 0.
1012-2A
1016-1A
Silicon 10, Copper 0.
1016-2A
As Cast
Machined

FIG. 8.

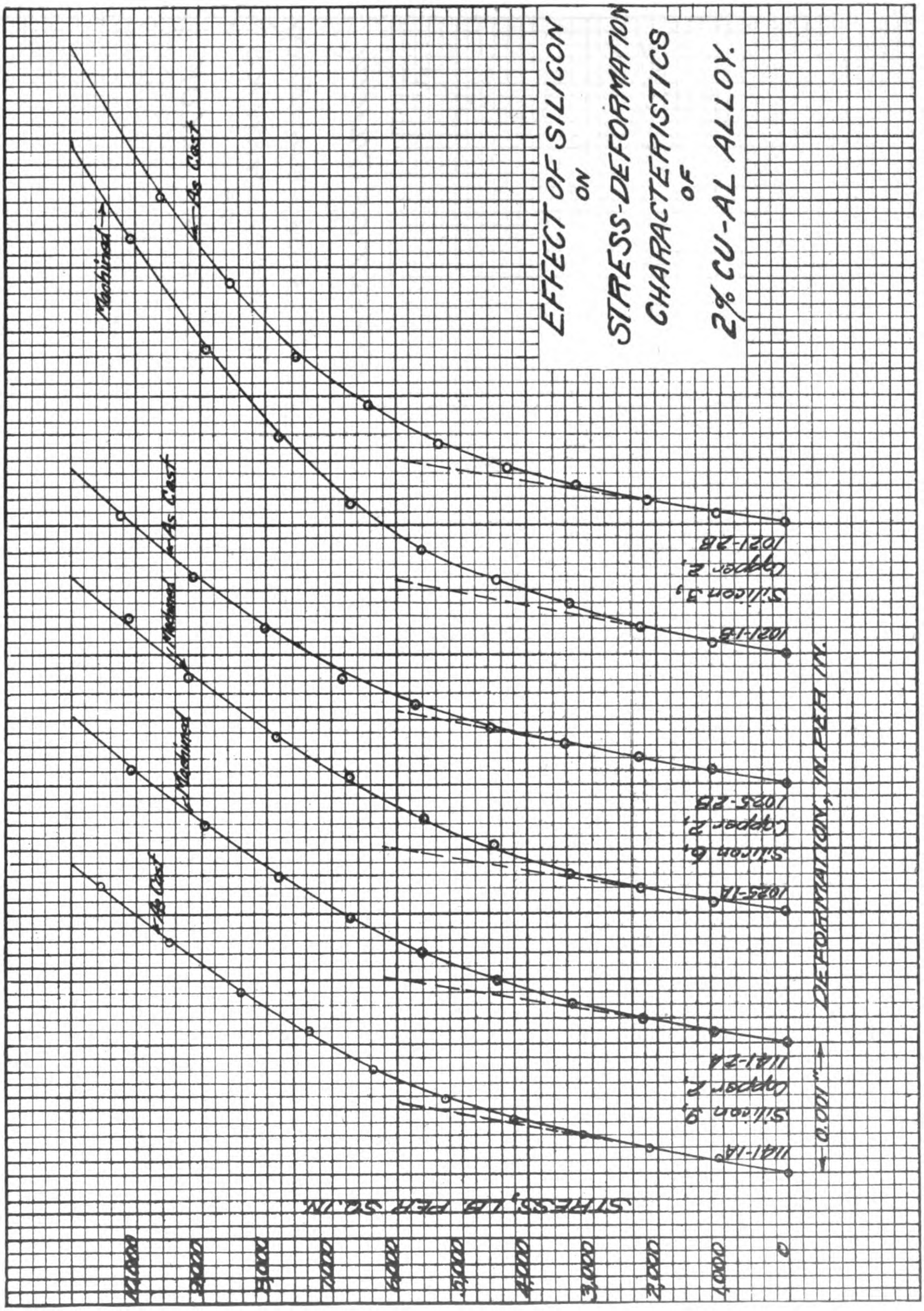

EFFECT OF SILICON
ON
STRESS-DEFORMATION
CHARACTERISTICS
OF
2% CU-AL ALLOY.
Machined
As Cast
Silicon 3,
Copper 2,
1021-2B
1021-1B
Silicon 6,
Copper 2,
1025-2B
1025-1B
Silicon 9,
Copper 2,
1121-2A
1121-1A
STRESS, LB PER SQ. IN.
0.001" DEFORMATION, IN. PER IN.
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000

FIG. 9.

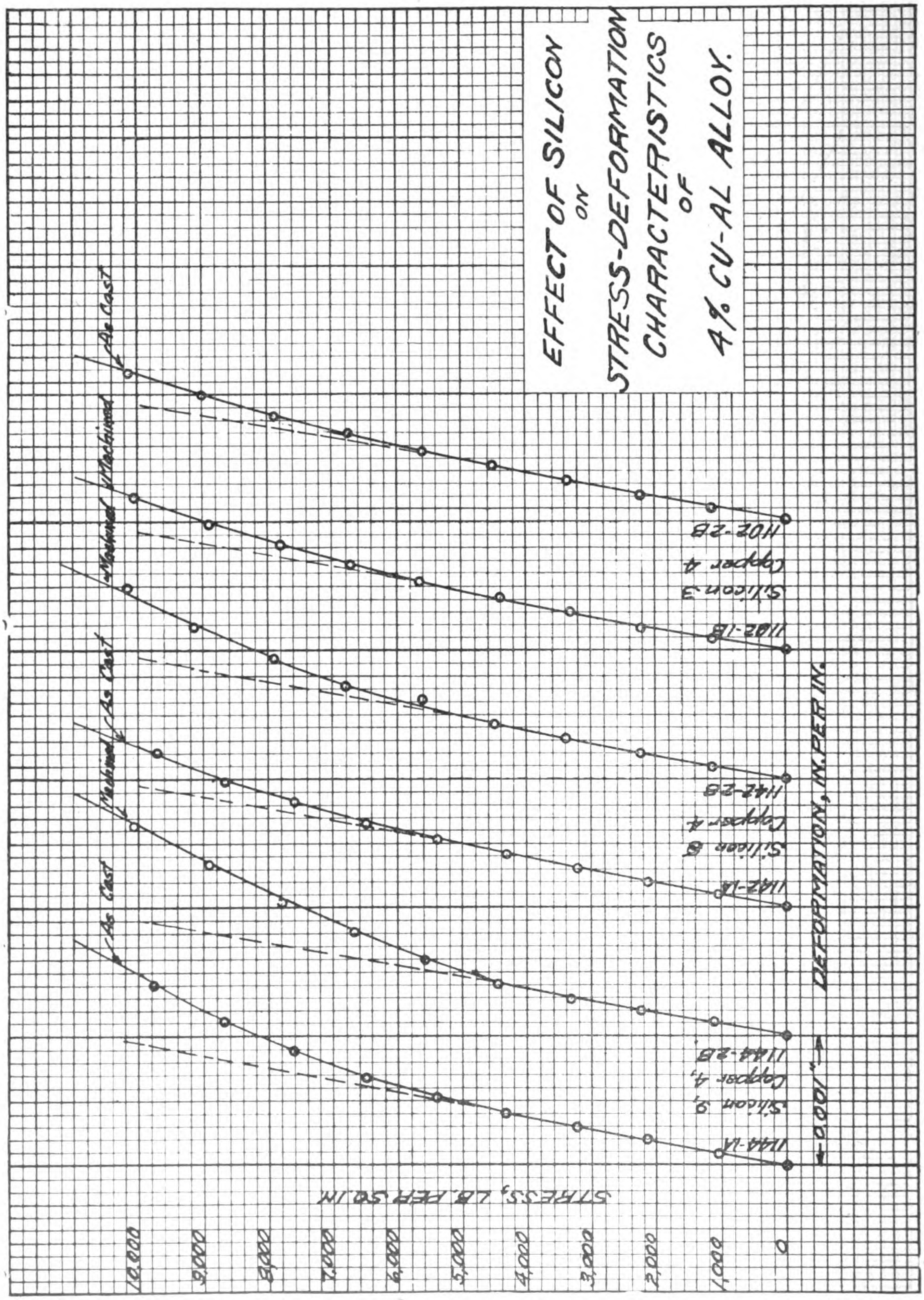

EFFECT OF SILICON
ON
STRESS-DEFORMATION
CHARACTERISTICS
OF
4% CU-AL ALLOY.
As Cast
Machined
Machined
Machined
As Cast
Machined
As Cast
1102-2B
Copper 4
Silicon 3
1102-1B
1142-2B
Copper 4
Silicon 6
1142-1B
1144-2B
Copper 4,
Silicon 9,
1144-1A
DEFORMATION, IN. PER IN.
← 0.001 →
STRESS, LB. PER SQ. IN.
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0

FIG. 10

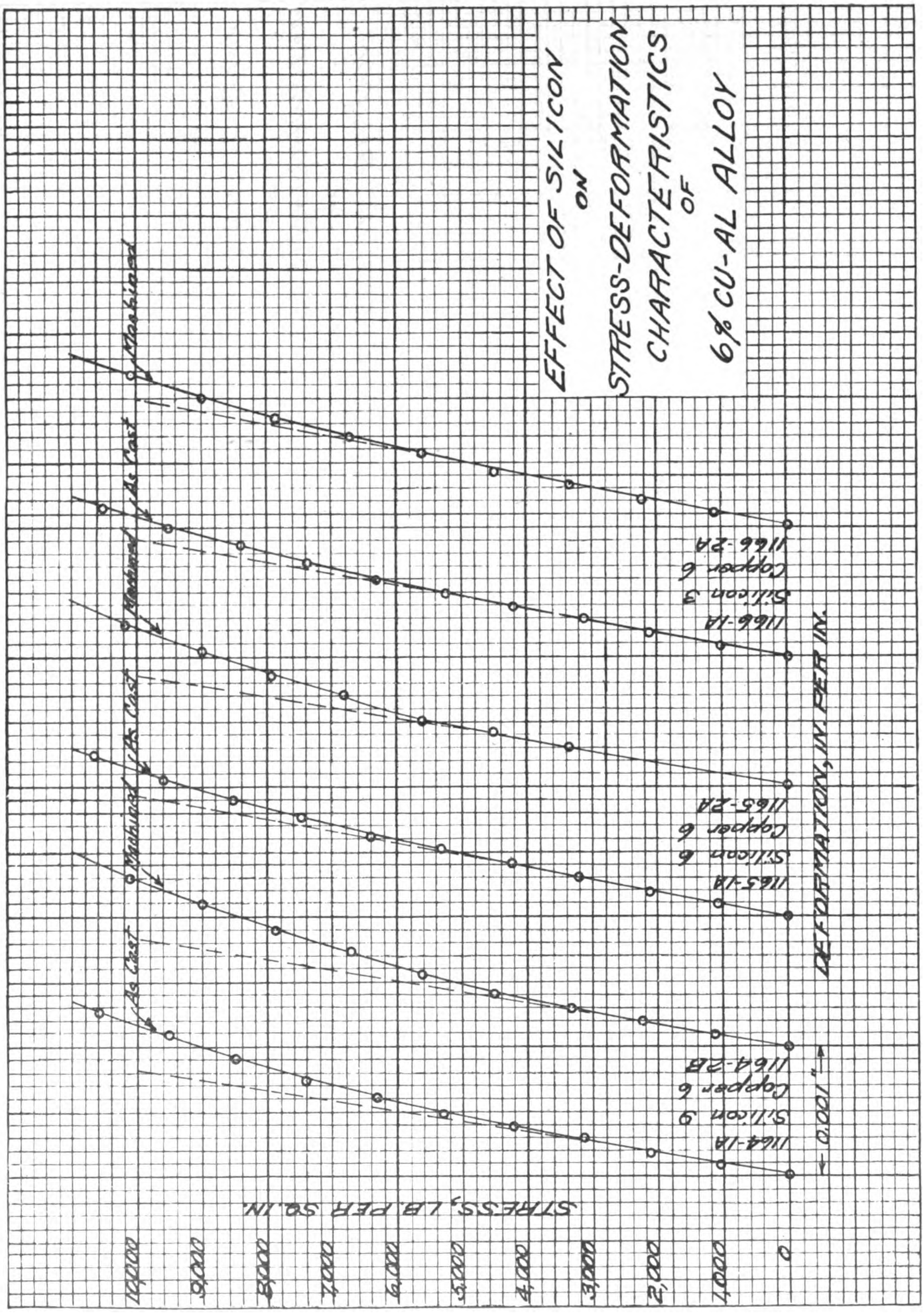
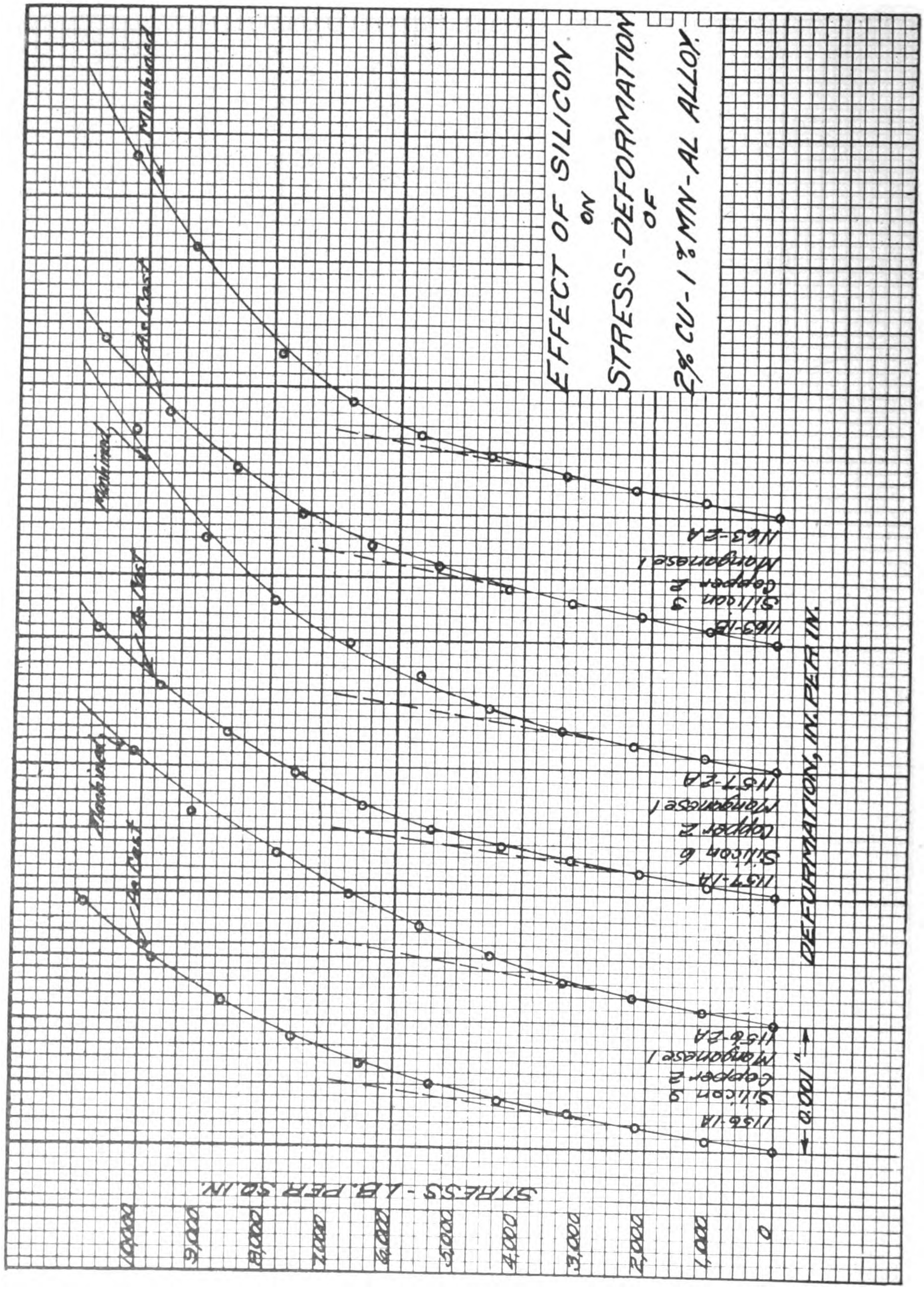
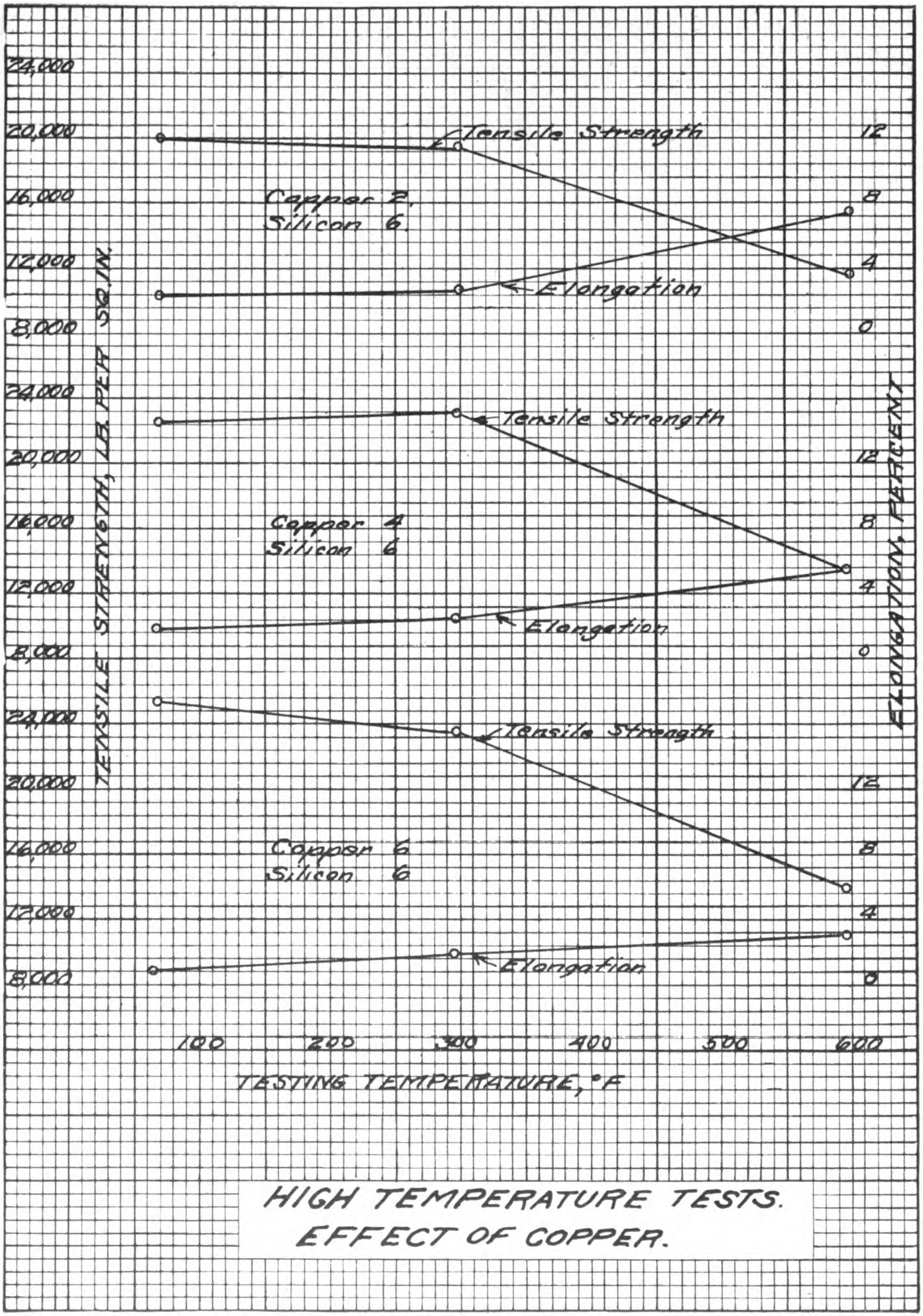

EFFECT OF SILICON
ON
STRESS-DEFORMATION
CHARACTERISTICS
OF
6% CU-AL ALLOY
Machined
As Cast
Machined
As Cast
Machined
As Cast
1166-1A
Silicon 3
Copper 6
1166-2A
1165-1A
Silicon 6
Copper 6
1165-2A
1164-1A
Silicon 9
Copper 6
1164-2B
← 0.001" →
DEFORMATION, IN. PER IN.
STRESS, LB. PER SQ. IN.
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0

Fig. 11.



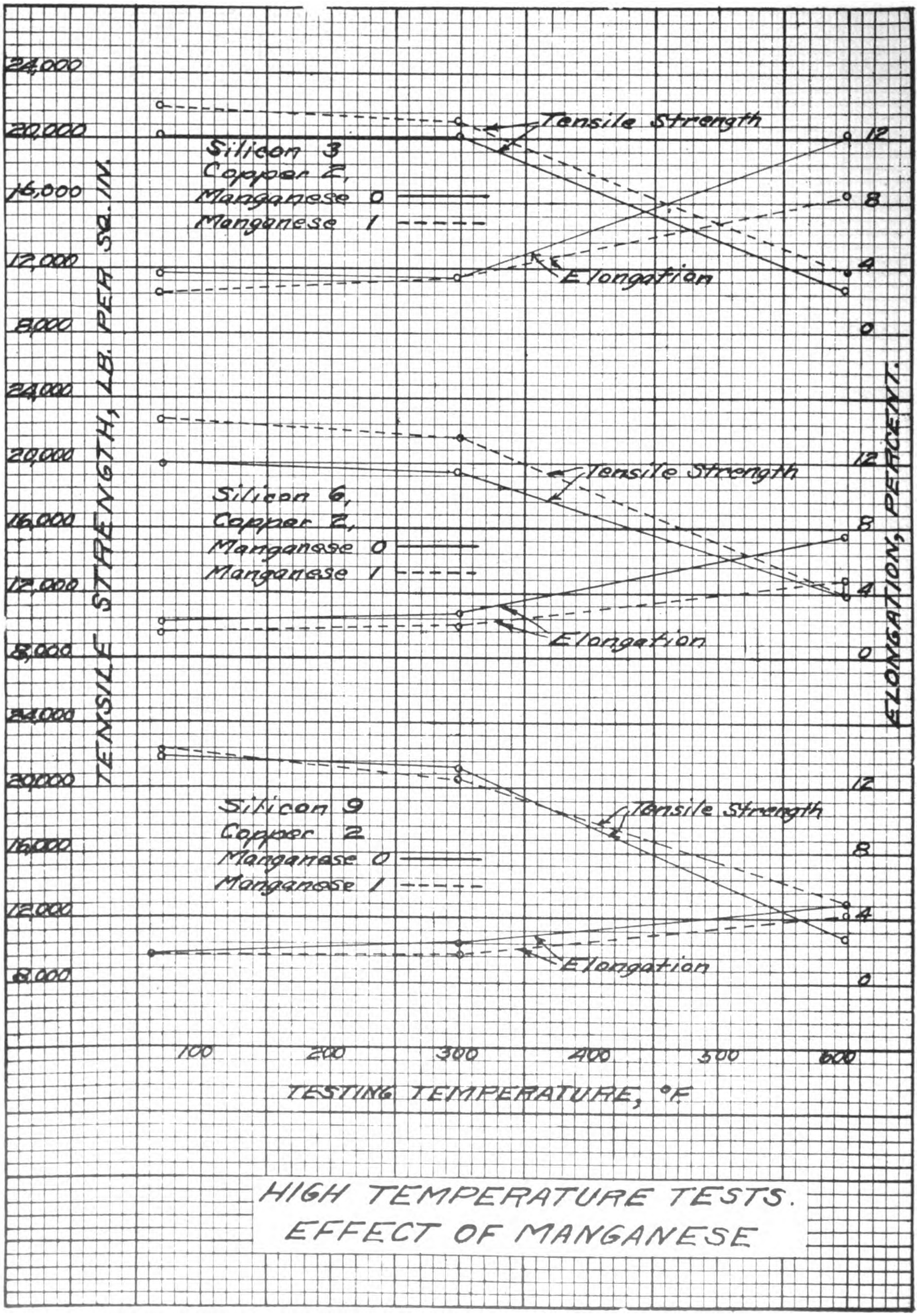
EFFECT OF SILICON ON STRESS-DEFORMATION OF 2% CU-1% MN-AL ALLOY.
Machined
As Cast
Machined
As Cast
Machined
As Cast
1163-2A
1163-1B
Silicon 4
Copper 2
Manganese 1
1157-2A
1157-1A
Silicon 6
Copper 2
Manganese 1
1156-2A
1156-1A
Silicon 2
Copper 2
Manganese 1
DEFORMATION, IN. PER IN.
0.001"
STRESS - LB. PER SQ. IN.
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0

FIG. 12.



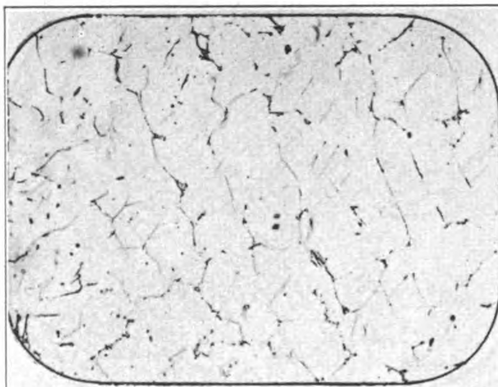
24,000
20,000
16,000
12,000
8,000
24,000
20,000
16,000
12,000
8,000
24,000
20,000
16,000
12,000
8,000
TENSILE STRENGTH, LB. PER SQ. IN.
Tensile Strength
Copper 2
Silicon 6
Elongation
Tensile Strength
Copper 4
Silicon 6
Elongation
Tensile Strength
Copper 6
Silicon 6
Elongation
12
8
4
0
12
8
4
0
12
8
4
0
ELONGATION, PERCENT
100
200
300
400
500
600
TESTING TEMPERATURE, °F
HIGH TEMPERATURE TESTS.
EFFECT OF COPPER.

FIG. 13.

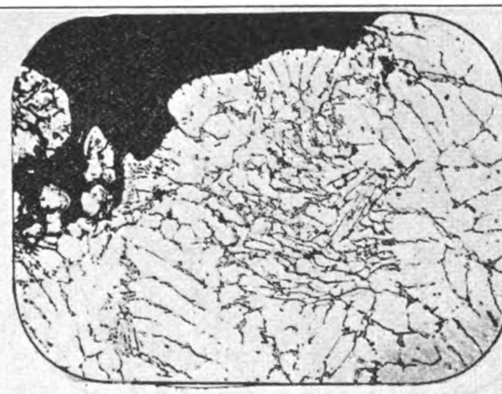


TENSILE STRENGTH, LB. PER SQ. IN.
ELONGATION, PERCENT.
24,000
20,000
16,000
12,000
8,000
Tensile Strength
Elongation
Silicon 3
Copper 2,
Manganese 0
Manganese 1
Silicon 6,
Copper 2,
Manganese 0
Manganese 1
Silicon 9
Copper 2
Manganese 0
Manganese 1
12
8
4
0
100
200
300
400
500
600
TESTING TEMPERATURE, °F
HIGH TEMPERATURE TESTS.
EFFECT OF MANGANESE

FIG. 14.



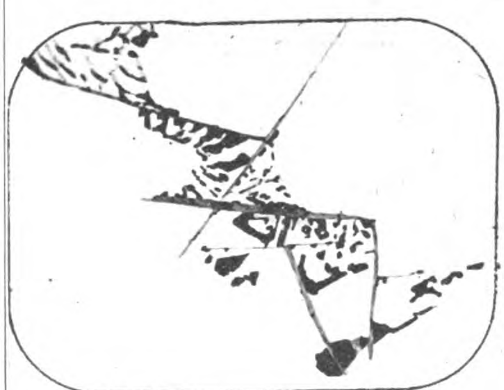
(a) 100 X
Aluminum solid solution matrix and network of impurities.



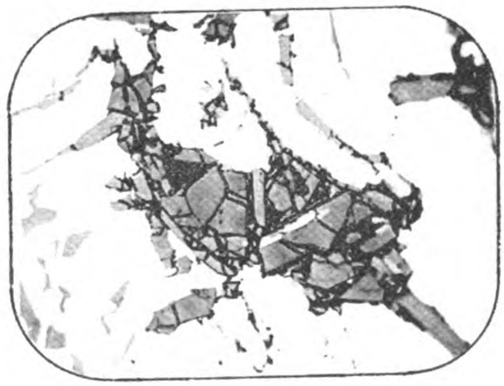
(a) 100 X
Impurities segregated near pipe at centre of test specimen. Compare Fig.15-A.

(b) 500 X
Needles, probably $FeAl_3$, and Si eutectic (black).

(b) 500 X
Shows nature of network in this segregated area.



(c) 1000 X
Shows contrast between $FeAl_3$ needles (light) and Si eutectic particles (black).



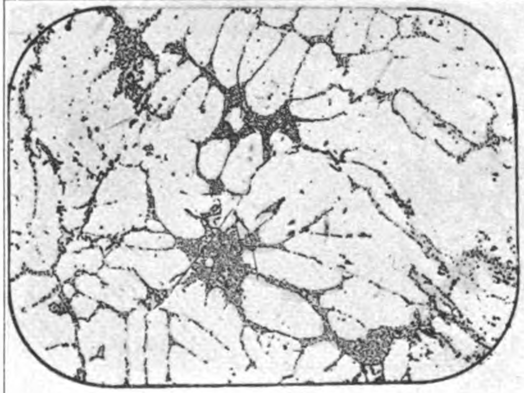
(c) 1000 X
Probably "X constituent," containing Fe and Si. Appears same color as needles in Fig.15-C and has same etching characteristics.

Fig. 15 - Normal Structure.

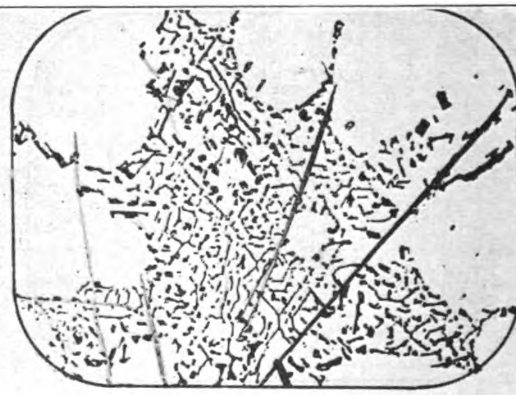
Fig. 16 - Segregated Area.

Unetched.

Structure of 3/4 in. diameter sand cast test bar of aluminum ingot (Melt 920, Si 0.99, Cu 0.32, Fe 0.51).



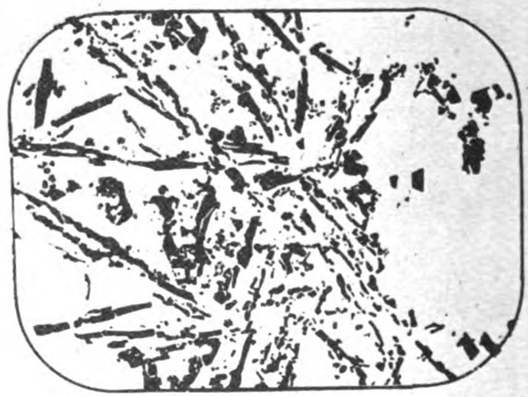
(a) 100 X
Average Structure.



(b) 500 X
Si-Al eutectic and light needles probably $FeAl_3$.

Fig. 17 (Melt 1010, Cu 0.41, Si 4.12, Fe 0.59).

(a) 100 X
Average Structure.



(b) 500 X
Coarse Si-Al eutectic, see centre of Fig. 18-A.

Fig. 18 (Melt 1012, Cu 0.42, Si 6.20, Fe 0.90).

(a) 100 X
Average Structure.

(b) 500 X
Particles of Si eutectic dark and lighter cubes of unknown composition.

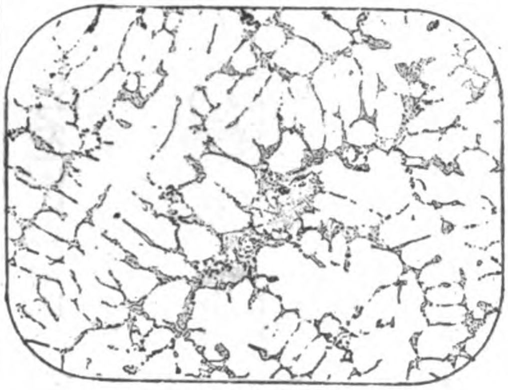
Fig. 19 (Melt 1016, Cu 0.34, Si 5.34, Fe 0.73).

Structure of 3/4 in. diameter sand cast test specimens of the Silicon-Aluminum Alloys.

(a) 100 X
Average Structure.

(b) 500 X
Black, Si; half tone probably $FeAl_3$ or "X Const.;" light, $CuAl_2$; matrix, aluminum solid solution.

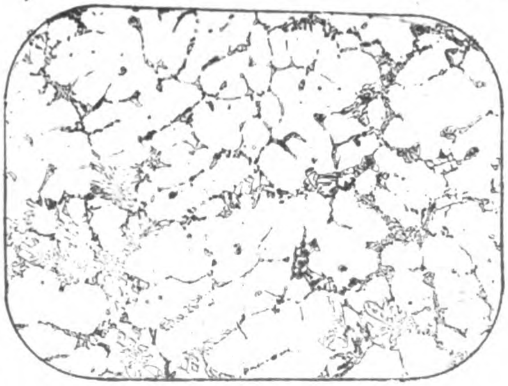
Fig. 20 (Melt 1036, Cu 4.25, Si 3.41, Fe 0.74).



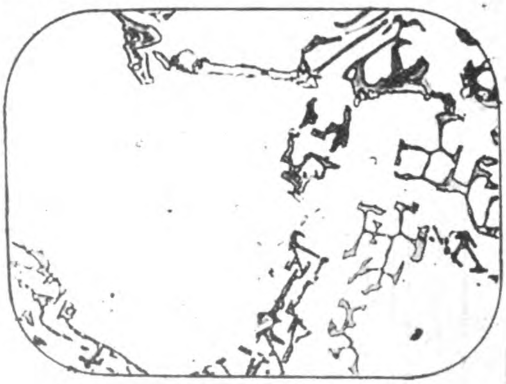
(a) 100 X
Average Structure.

(b) 500 X
Si, black; light rounded particles, $CuAl_2$; dendritic structure, probably $FeAl_3$ or "X Const.;" needles probably $FeAl_3$.

Fig. 21 (Melt 1C48, Cu 6.39, Si 3.90, FeC.77).



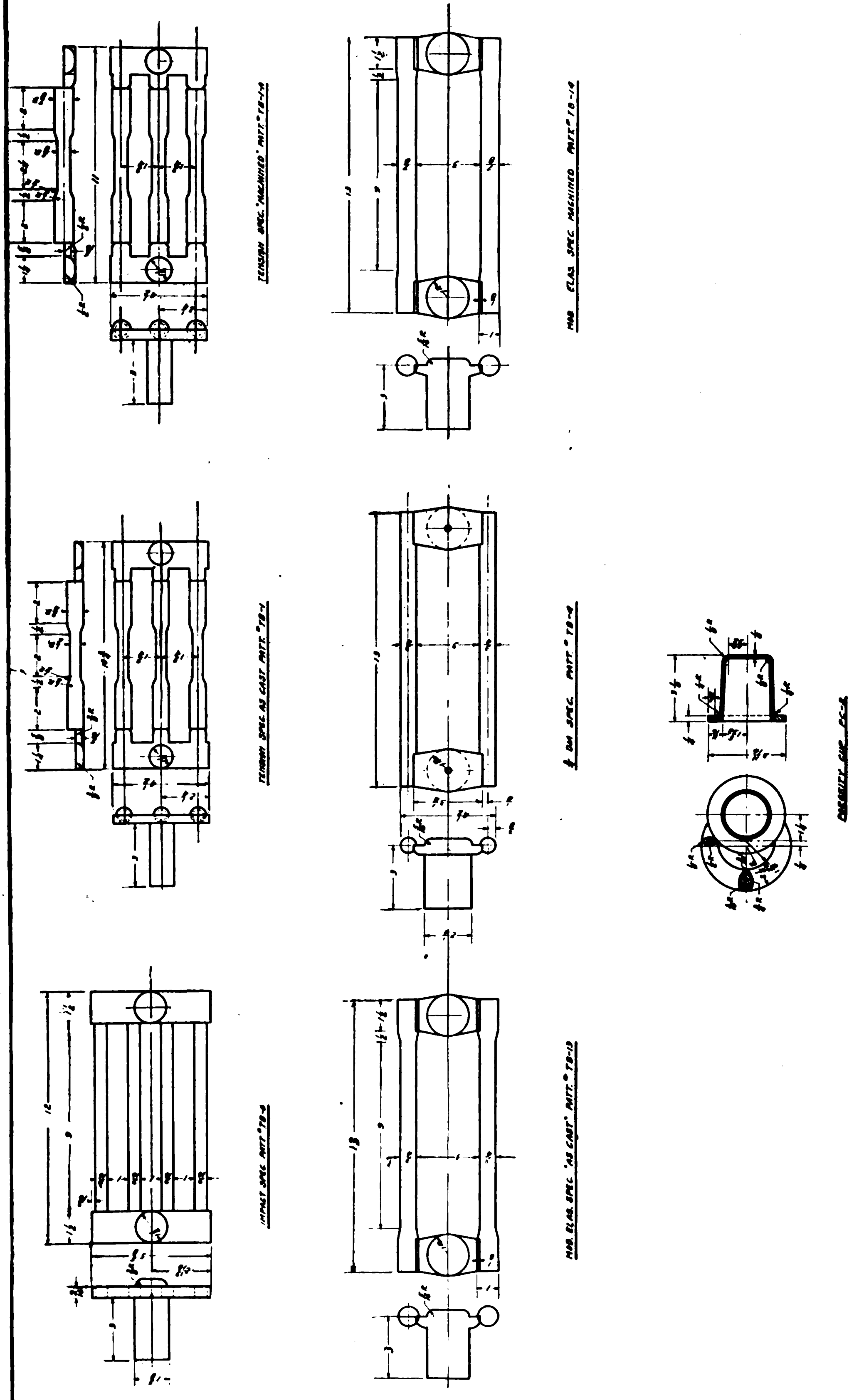
(a) 100 X
Average Stfucture.



(b) 500 X
Characteristic swastika form of constituent which appears with addition of manganese.

Fig. 22 (Melt 1071, Cu 2.33, Si 3.86, Fe 0.65, Mn 0.87).

Structure of 3/4 in. diameter sand cast test specimens of the Copper-Silicon-Aluminum Alloys with and without Manganese.



TEST BAR PATTERNS

Fig. 23.

ADDENDUM I.

AGING TESTS ON COPPER-SILICON-ALUMINUM ALLOYS.

The following table gives a summary of the aging tests made on some of the copper-silicon-aluminum alloys which were investigated in this report. The figures for the "As cast," the 9 months' aging, and the 15 months' aging tests are the averages of five tension tests; and the figures for the 30 days' aging are the averages of three tension tests.

These results show that there is no noticeable change in tensile properties with time after casting in the copper-silicon-aluminum alloys containing up to 6 per cent copper and 9 per cent silicon.

AGING TESTS.

	"As cast."	30 days' aging.	9 months' aging.	15 months' aging.
Melt No. 1010—Cu 0.41, Si 4.12, Fe 0.59.				
Tensile strength, pounds per square inch	18,120	19,520	19,260	19,250
Elongation, per cent in 2 inches	4.9	5.3	4.0	4.5
Melt No. 1012—Cu 0.42, Si 6.20, Fe 0.90.				
Tensile strength, pounds per square inch	19,800	21,520	19,800	20,810
Elongation, per cent in 2 inches	4.2	4.2	4.25	4.5
Melt No. 1016—Cu 0.34, Si 9.34, Fe 0.73.				
Tensile strength, pounds per square inch	18,980	20,120	18,430	18,840
Elongation, per cent in 2 inches	2.8	2.5	3.0	2.5
Melt No. 1036—Cu 4.25, Si 3.41, Fe 0.74.				
Tensile strength, pounds per square inch	21,740	23,970	23,360	22,440
Elongation, per cent in 2 inches	2.2	1.7	1.5	1.0
Melt No. 1044—Cu 4.26, Si 10.12, Fe 0.70.				
Tensile strength, pounds per square inch	22,540	23,640	23,850	24,990
Elongation, per cent in 2 inches	0.9	0.5	1.3	1.0
Melt No. 1048—Cu 6.39, Si 3.90, Fe 0.77.				
Tensile strength, pounds per square inch	23,210	23,380	27,260	26,930
Elongation, per cent in 2 inches	0.9	1.0	1.16	0.5
Melt No. 1069—Cu 6.29, Si 9.00, Fe 0.66.				
Tensile strength, pounds per square inch	24,170	24,990	25,020	25,570
Elongation, per cent in 2 inches	1.0	1.3	1.0	0.5

File D 52.1/D. H. M. 2/2 — McCOOK FIELD REPORT, SERIAL No. 1977

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV — November 1, 1922 — No. 386

PERFORMANCE TEST OF U. S. MAIL DH-M2

(PERFORMANCE TEST REPORT No. 89)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
July 18, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

OFFICIAL PERFORMANCE TEST OF U. S. MAIL, DH-M2.

SUMMARY OF RESULTS.

Date, May 5, 1922.

Airplane, U. S. Mail. No. 255.

Type, DH-M2. Engine, Liberty "12."

Propeller, Dwg. No. 34555. Equipped as mail plane.

	Pounds.
Weighty empty (including water)	3,190
Armament and equipment (600 pounds ballast in mail pit)	633
Crew	180
Gasoline	653
Oil	56
Weight loaded	4,712

Weight (square foot), 9.4 pounds (500 square feet).

Weight (horsepower), 11.35 pounds (415 horsepower at 1,750 R. P. M.).

Fineness, 103.8; Ae 14.5.

Standard altitude in feet.	Climb. Time in minutes.	Climb. R.P.M.	Climb. Rate (feet) in minutes.	Climb. Flow (gallons per hour).	Speed. M.P.H.	Speed. R.P.M.	Speed. Flow (gallons per hour).
0	......	1,570	900	....	121.7	1,750	....
6,500	9.03	1,555	560	....	117.8	1,695	....
10,000	16.5	1,540	380	....	114.0	1,650	....
15,000	38.2	1,505	130	....	104.0	1,550	....
20,000	....	....	....	....	....	....	....
25,000	....	....	....	....	....	....	....
15,500 service ceiling	42.7	1,500	100	....	101.7	1,535	....
17,400 absolute ceiling	......	1,480	0	....	83.5	1,480	....

Endurance, full throttle at 10,000 feet (including climb), 4¼ hours.

Minimum speed at sea level (lowest throttle), 63.3.

Landing speed, 59.9 M. P. H.

DISTRIBUTION OF WEIGHTS.

	Pounds.
Weight empty (with water)	3,190
Armament and equipment (600 pounds ballast in mail pit)	633
Crew	180
Gasoline	653
Oil	56
Weight loaded	4,712
Weight on front wheels (tail skid on ground)	4,144
Weight on tail skid (tail skid on ground)	568
Weight on front wheels (flying position)	4,351
Weight on tail skid (flying position)	361

Center of gravity (distance from wheels in flying position), 16.8 in aft of center line of axle.

Provisions for special equipment not carried during test.

PILOT'S OBSERVATIONS.

FLYING QUALITIES.

Taxying: Easy to taxi.

Take-off: Response to controls good. Takes off easily with the usual run for this type.

Landing: Easy and slow. No tendency to spin on the ground. Very good glide.

Stability: Lateral; very good. Longitudinal; adjustable stabilizer O. K. Stalls very slowly, but on stalling falls off to the left slowly.

Maneuverability: Ease of control, good. Response to control, good. Handles easily in maneuvers for this type. Holds steep banks well and turns within a short radius. Do not recommend this airplane for any stunting whatever.

VISIBILITY.

O. K. except forward and downward; the visibility is cut off by the lower wing, making it a little difficult in a forced landing.

MAINTENANCE.

This airplane, during the time flown on test, gave very little maintenance trouble. Recommend the engine mounting be strengthened, as well as the center section fittings, struts and cables. Recommend gas system be changed to syphon pump or wind-driven pump.

SUMMARY.

The flying qualities of this airplane are very good, having plenty of reserve climb and stalling very slowly.

The wheel is too large, which results in the cockpit being very crowded. Recommend a smaller control wheel be used. The pilot's seat could also be changed to give the pilot more comfort.

DESCRIPTION OF POWER PLANT.

ENGINE.

Make, Liberty. Factory, No. 1716. A. S. No. 31315. Type, 12 cylinder, vertical 45°. Number in plane, 1. Location, front of fuselage. Rated horsepower, 400. Rated revolutions per minute, 1,700. Bore, 5 inches. Stroke, 7 inches. Compression ratio, 542 to 1. Weight dry, 845 pounds. Gas consumption, 0.496 pound horsepower per hour. Oil consumption, 0.032 pound horsepower per hour. Weight of water in engine, 45 pounds.

IGNITION.

Battery or magneto, battery. Make, Delco. Number, ———. Advance, degrees, 30°. Gas interrupter, ———.

Distributor, ———. Plugs: Make, B. G. Type, metal body, porcelain insulation. Gap, 0.020.

CARBURETORS.

Make, Zenith. Type, double jet, double venturi. Number, 2. Setting jet, 1.65 m/m. Choke, 36 m/m. Compensator, 1.70 m/m. Gas drains, 3/8 tubing leading out of fuselage. Air intake, straight scoop. Mixture control, manual operated.

RADIATORS.

Make, B. Type, ribbon core. Number, 1. Position, nose of fuselage. Frontal area, 5.9. Depth, 5 inches. Length, 49 inches. Width, 29 inches. Radiator surface, 312 square feet. Temperature adjustment, shutters. Water capacity, 81 pounds. Flow, satisfactory. Thermometer: Make, Boyce. Weight, 179 pounds, full. Type, ———. Water capacity of whole system, 131 pounds. Allows full climb without boiling when temperature is approximately 75–80° F.

EXHAUST PIPES.

Description, individual stocks for each cylinder merging into manifold for each bank.

LUBRICATION.

Capacity oil tank, 7 gallons. Dimensions oil tank ——— Oil used (brand), Liberty. Oil pressure, 34. Oil temperature, no oil thermometer. Type pump, gear. Wet or dry sump, dry. If wet, capacity ———. Description lubrication system: Force feed to all main bearings, connecting rods, and cam shafts, spray to cylinder walls and wrist pins.

FUEL SYSTEM.

Number of tanks: 1 main; 1 gravity. Location, between mail compartment and cockpit. Capacity, main pounds, 103 gallons. Capacity, reserve pounds, 9 gallons. Material, terne plate. Gauge, 18. Description of fuel-supply system, air-pressure system.

ENGINE CONTROL.

Description, rod and lever.

PROPELLER.

Make, Engineering Division. Number blades, 2. Diameter, 9 feet 2 inches. Pitch 6.98′. Tips, terne plate. Clearance, ———. Dwg. No. 34555. A. S. No. 74608.

DESCRIPTION OF AIRPLANE.

DIMENSIONS.

Overall span, 48 feet 8 inches.
Overall length, 30 feet 2½ inches.
Overall height, 11 feet 5 inches.
Height at hub of propeller above ground ———.
In flying position, ———.
At rest, ———.

AIRPLANES.

Wing curve, R. A. F. 15.
Sweepback, none.
Dihedral, degrees, 3°.
Stagger, 8 inches.
Total area including ailerons, ———.
Gap, 5 feet 6 inches.

UPPER PLANE.

(Including center section.)

Span, 48 feet 8 inches.
Chord, 5 feet 6 inches.
Area, with ailerons: Total upper and lower, 500 square feet.
Incidence, degrees, 3°.

LOWER PLANE.

Span, 48 feet 8 inches.
Chord, 5 feet 6 inches.
Area, see above.
Incidence, degrees, 3°.

AILERONS OR FLAPS.

Number, 4.
Arrangement, ———.
Upper length, ———.
Upper chord, ———.
Upper area, 36.6.
Lower length, ———.
Lower chord, ———.
Lower area, 36.6.
Total area, 73.2.
Distance from center of ailerons to longitudinal axis of airplane, ———.

CENTER SECTION.

Area, ———.
Dimensions, ———.
Contents, ———.

STABILIZER.

Area, 37.2 square feet.
Setting, ———.

ELEVATOR.

Area, 23.6 square feet.
Distance from leading edge of elevator to center of gravity of airplane, ———.

RUDDER.

Area, 15.8 square feet.
Distance from leading edge of rudder to center of gravity of airplane, ———.

FUSELAGE.

Maximum cross-section shape, ———.
Maximum cross-section area, ———.
Maximum cross-section dimension, ———.
Distance of maximum section from leading edge, lower plane, ———.

LANDING GEAR.

Number of wheels, ———.
Tread, ———.
Shock-absorbing system, ———.
Braking device, ———.
Wheels ahead of center of gravity, ———.

FIN.

Area, 5.6 square feet.

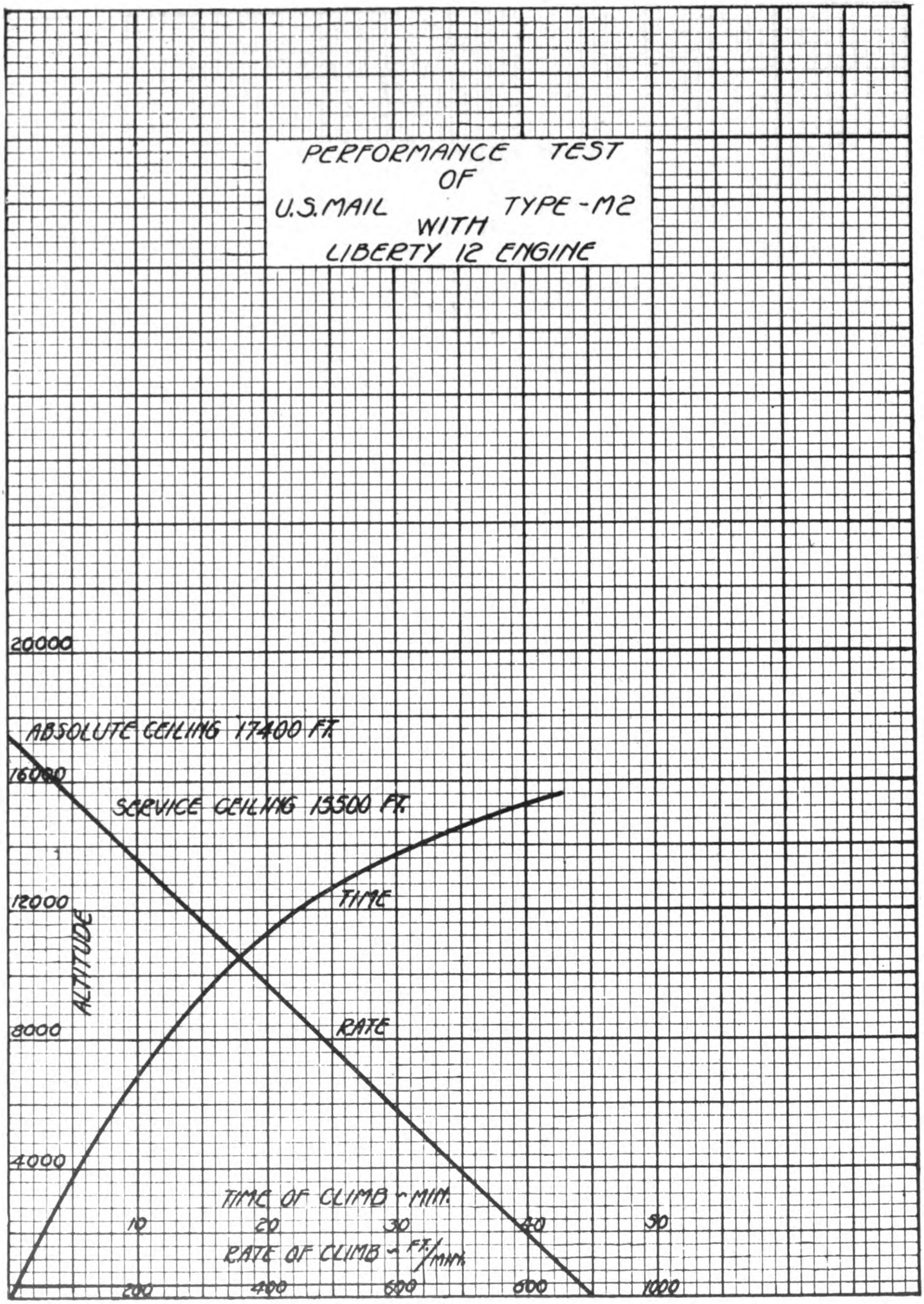

PERFORMANCE TEST
OF
U.S. MAIL TYPE - M2
WITH
LIBERTY 12 ENGINE
20000
ABSOLUTE CEILING 17400 FT.
16000
SERVICE CEILING 15500 FT.
12000
TIME
ALTITUDE
8000
RATE
4000
TIME OF CLIMB ~ MIN.
10
20
30
40
50
RATE OF CLIMB ~ FT./MIN.
200
400
600
800
1000

FIG. 1.

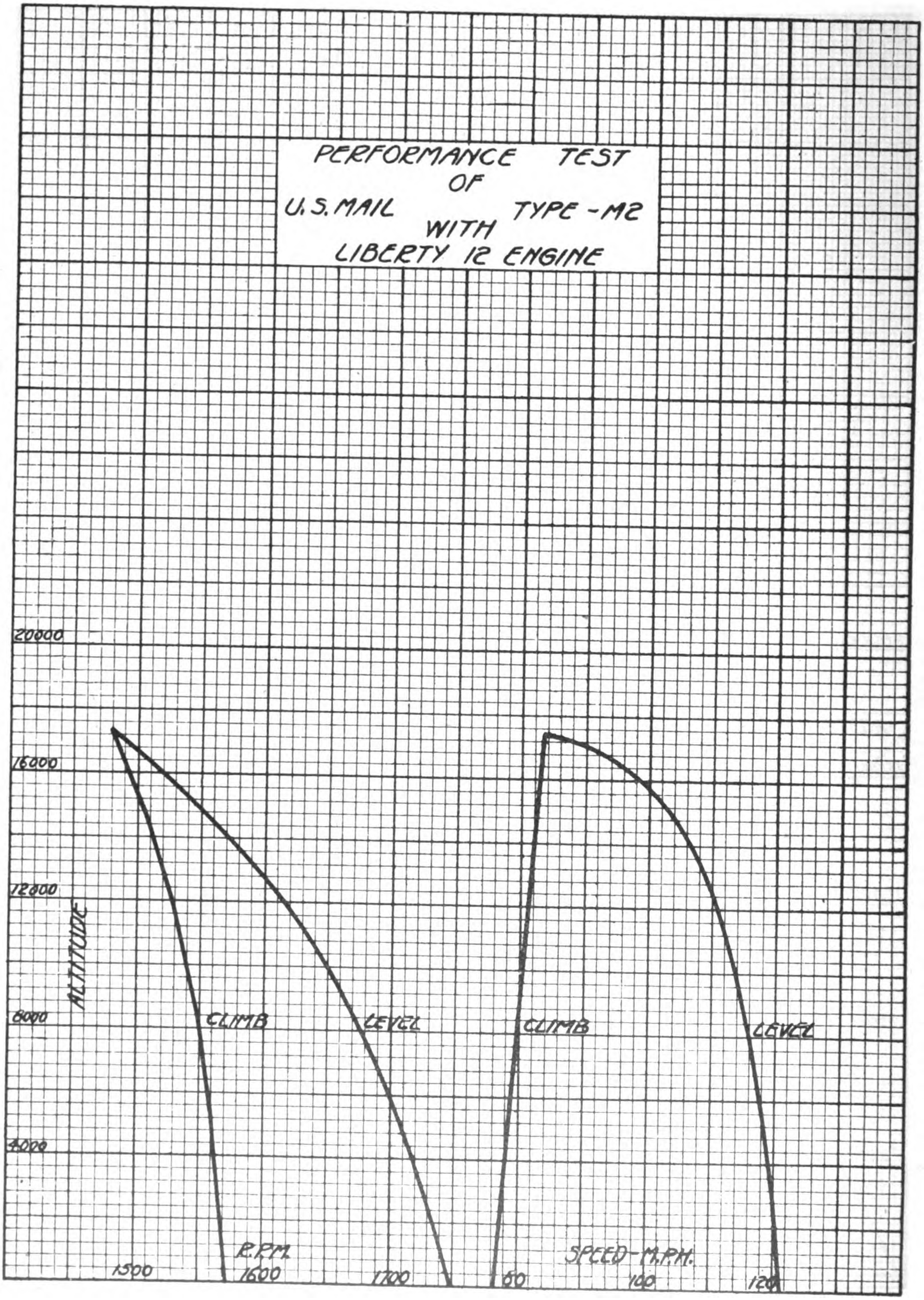

PERFORMANCE TEST
OF
U.S. MAIL TYPE - M2
WITH
LIBERTY 12 ENGINE
20000
16000
12000
8000
4000
ALTITUDE
CLIMB
LEVEL
CLIMB
LEVEL
R.P.M.
1500
1600
1700
SPEED - M.P.H.
80
100
120

FIG. 2.

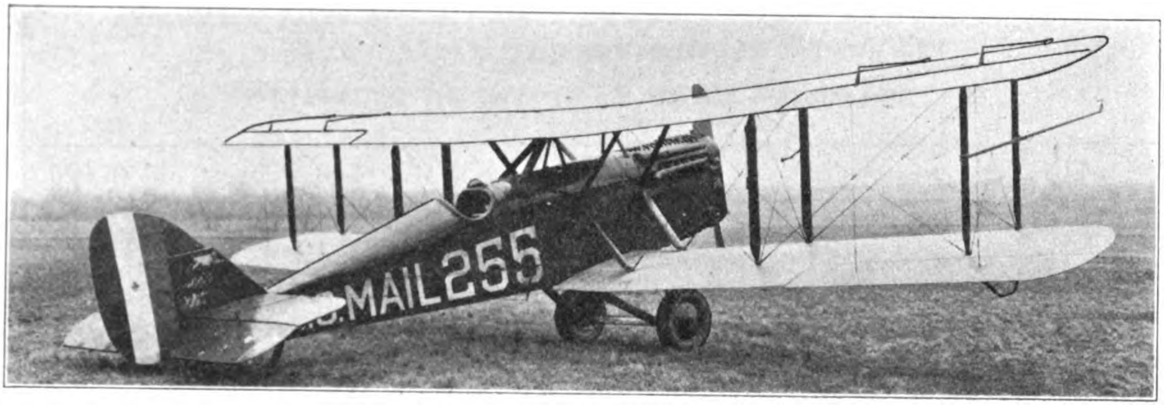


FIG. 3.

FIG. 4.

FIG. 5.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV January 2, 1923 No. 387

AIRPLANE WING FITTINGS

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by R. A. Miller
Engineering Division, Air Service
McCook Field, Dayton, Ohio
July 7, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

AIRPLANE WING FITTINGS.

INTRODUCTION.

It is the intention in this report to discuss the various wing fittings that are in use at the present time, pointing out the good and bad features of each. No attempt will be made to recommend or to design a standard set of fittings, as, at the present stage of airplane development, the variety of designs, truss arrangements, spar shapes, and materials is too great. Likewise, the scope of this discussion will be confined to fittings in use on wood spars, as it is felt that there has not been sufficient time and opportunity to make much progress in developing metal construction. However, a great deal of this discussion applies to wing fittings with metal spars as well as with wood spars.

GENERAL PROPERTIES.

The function of wing fittings is to connect the various structural members together so as to hold them firmly in their true relation to each other and to transfer and distribute the various stresses. A properly designed fitting should have the necessary strength, a minimum of weight, and as uniform a distribution of material as possible. It should be compact and rigid, and develop no serious eccentricities. The fitting should be so designed that it is easily assembled on the airplane, is easily replaced, and can be rapidly and economically produced.

It is quite obvious that the fitting should have the requisite strength with the least weight possible. The fitting should be strong enough to develop the full strength of all structural members attached to it. At the same time the fitting should be well proportioned, so that its strength throughout will be as nearly uniform as possible.

It is very difficult to eliminate all eccentric stresses from a fitting and yet have a fitting that is light in weight, easy to manufacture, and easy to assemble on the airplane. Poor design might easily result in eccentric stresses that would be more severe than the primary stresses resulting from flying or landing conditions. It might be well to point out that an eccentricity that decreases the moment at the strut point will increase the moment in the span, and an eccentricity that decreases the moment in the span will increase the moment at the strut. Great care should be exercised in the design, so that any eccentric stresses that may result will be so small as to be negligible.

The fitting should be sufficiently strong and rigid so that the position of no part of it can be changed by the loads that may come upon the structure. This is especially true of drag-truss fittings, as, once the airplane is completed it is impossible to inspect them without removing the fabric from the wings. If a fitting should bend, twist, or give, it might throw the structure out of line, resulting, perhaps, in a decrease in the performance of the airplane, excessive stress in some member, or even in the destruction of the airplane. The fitting should be as compact as possible, so as not to interfere with the other parts of the airplane and, in the case of external fittings, so as to cause as little wind resistance in flight as possible.

A fitting might be quite economical as to material, have sufficient strength, and yet be a very poor production job. An assembly of thin and thick pieces, or poor arrangement of lightening holes, might result in a fitting that would be exceedingly difficult to braze, weld, or heat-treat successfully. Material should be used that is readily obtained and the fitting should be so designed that it may be quickly and easily manufactured.

Ease of assembly on the airplane and ease of replacement are also important, and the fitting should be designed so that it may be assembled in position on the airplane or replaced with a minimum of disturbance of the other parts of the structure.

The best method of attaching metal fittings to a wood spar is by means of bolts. Wood screws do not give as rigid and positive a connection, and rivets should never be used, as driving the rivets tends to enlarge the hole and thus to weaken the spar. The fittings should never be attached to the spar by vertical bolts through the spar, as vertical holes in the spar weaken it materially through loss of area and reduction of the moment of inertia in the plane of the greatest bending moments. Vertical bolts that straddle the spar should be used or horizontal bolts through the spar near its neutral axis. The use of horizontal bolts is very satisfactory, as a fitting of this type usually has no eccentricities, and if the bolts are kept close to the neutral axis the holes have little effect upon the strength of the spar.

BRAZING AND WELDING.

When a permanent joint is made in assembling a wing fitting the pieces should be brazed together. A weld will transmit compressive stresses successfully and is a satisfactory method to use at the ends of struts when the material is low-carbon steel. But a weld can not be depended upon to take tension and should never be used when it will be subjected to heavy bending or tensile stresses. High-carbon, alloy, or heat-treated steels should never be welded, as welding reduces their strength considerably. Subsequent heat treatment will not help materially, as the excessive temperature of the welding operation has burned more or less of the carbon out of the steel. Brazing heat-treated steels somewhat reduces their ultimate strength, and fittings of heat-treated steels should be subjected to heat treatment after the brazing operation in order to bring out the full strength of the material. Heat treatment is feasible if a spelter with a sufficiently high melting point has been used in the brazing operation. Wing fittings should not be soldered, as the strength of soldered joints is very low and the joints are not dependable. However, splices in steel wire cables should be soldered and plugs in the ends of metal struts may be riveted and soldered.

SPAR FITTINGS.

Wing fittings may be divided into three general groups—interplane fittings, internal or drag-truss fittings, and couplings to attach the wings to the fuselage or center section. The first group includes the connection between the interplane struts, the lift and landing wires, the incidence wires, and the spars. Various combinations of bolts with suitable heads, lug plates, sockets, yokes, and box fittings are used to tie these members together and to insure a firm and rigid connection between them and the spar. These combinations fall into four general types, and the numerous designs differ from these general types only in minor details.

The earlier practice in airplane design was to attach the interplane members to the spars by means of vertical bolts through the spars. In some designs the wires and struts were attached directly to the bolts, but more often they were attached to lug plates which were bolted to the spars. Attaching a flying wire directly to a vertical bolt in the spar causes a bending moment in the bolt, creates a serious eccentric moment in the spar, and transfers the vibratory stresses in the wire directly to the fiber of the spar adjacent to the bolt. This, of course, is very unsatisfactory. Attaching the wires to lug plates which are bolted to the spars by vertical bolts through the spars decreases the eccentric stresses in most cases and reduces the effect on the spar of the vibratory stresses from the wires. Fittings consisting of vertical bolts in the spar and washers or lug plates are light in weight, are easily assembled, and are easy to replace; but they materially reduce the strength of the spar.

The Vought VE–7, the DH–4, and the Pomilio airplanes furnish good examples of this type of fitting. In the Vought VE–7 the interplane members are fastened to a lug plate which is attached to the spar by two vertical bolts through the spar. The DH–4 design is slightly modified, as the incidence and lift wires are attached to a lug plate which is fastened to the spar by two vertical bolts in the spar, one of which has a forked head to receive the interplane strut, and by a third bolt which passes through a wood piece that is glued and taped to the inner side of the spar. This arrangement is shown in Figures 1 and 2. The Pomilio wing fitting (figs. 3 and 4) is worthy of note, as a good example of poor design. The designer placed a box fitting on the spar and then attached the wires and strut to the spar by means of a lug plate fastened to the spar by means of vertical bolts in the spar. The metal in this box fitting, excepting that portion which is immediately adjacent to the bolts, serves no purpose but to add weight to the wings.

The second general type includes the designs in which the fitting bolts are vertical and straddle the spar. Tie-plates or lug plates on both flanges act as bolt spacers and assist in distributing the loads. Good examples of this type of fitting are found on the Curtiss JN–4 (fig. 5) and the Orenco airplanes (figs. 6 and 7). It will be observed that wood pieces are glued, bolted, and sometimes taped to the sides of the spar, and the lug plates to which are attached the wires and struts are fastened to the spar by means of the vertical bolts in these wood pieces. The glue should not be depended upon too much, and horizontal bolts should be used to prevent the wood pieces from sliding along the spar. These horizontal bolts may also be used to carry the drag-truss lug plates. This type of fitting is light, easily assembled on the airplane, and is easy to replace. Care should be used in the design, more particularly with the thicker wing sections, so that any eccentricities developed will be so small as to be negligible.

A modification of this type is found on the Lepere U. S. A. C–11. In this design wood blocks were not used. The four vertical bolts which fix the picture-frame struts straddle the spar and the inner pair of bolts straddle the drag-strut fitting, being spaced by the strut plates at one spar flange and by a tie-plate at the other. The lift wire-lug plate has side pieces which lie across the sides of the spar to which it is fastened by two horizontal bolts which also carry the drag strut and wire fittings. In this design the safety factor is not so high as in the design with the wood pieces, and it is somewhat heavier. However, it is more easily installed and has given very satisfatory service. A sketch of the Lepere fitting will be found in Figure 23.

A minor advantage of the types of fittings using lug plates with vertical bolts is that the fabric may be placed on the wing more easily, as there will be no interference from projecting parts of the fitting.

The box fitting will be considered as the third general type. Designs of this type take the form of a box or sleeve which must be slid along the spar into position. It is extremely difficult to get a firm, tight fit, and if the spar is not tapered wood spacers must be used. It would be impossible to replace a fitting of this type without removing the fabric, ribs, and drag members of the wing. The wires and struts are attached to lugs which are brazed to the metal sleeve or formed in the extended sides of the fitting. The fitting should be fixed in position on the spar by horizontal bolts which may be also used to carry the drag strut and wire lug plates. This type of fitting is especially efficient in distributing the stresses coming into the spar, and it transfers stresses between interplane members and drag members largely through the metal fitting instead of through the spar. This type of fitting is somewhat heavy, difficult to assemble on the spar, and a great deal of trouble to replace. However, careful design should eliminate all serious eccentricities when a box fitting is used. Examples of this type of fitting are to be found on the Nieuport 27, the Salmson 2A2, and the GA–1.

A modification of this type of fitting will be found on the TW–1. (See figs. 8 and 9.) The box fitting is made in two pieces—a yoke that fits over the spar and a cover or tie-plate. Two vertical bolts, to which are attached the interplane struts, straddle the spar, passing through the cover plate, the flanges formed in the yoke, and through a plate brazed to the top of the yoke. The cover plate has lugs formed in it to which are attached the lift wires. Horizontal bolts fix the fitting in place on the spar. This fitting is easily assembled on the spar and would be very easy to replace. But it is a little heavier than a box fitting made in one piece, and because of the way the lift wires are attached to the spar by the two vertical bolts it develops serious eccentricities. This eccentricity is large enough so that the moment induced in the fitting caused crushing of the spar at the outer end of the fitting. In the effort to prevent the spar from crushing, this fitting was redesigned for the CO–2 and the fitting extended along

the spar until we have the extremely heavy fitting shown in Figure 10. However, the bolt arrangement remains the same, and in this particular case the eccentricity is large enough to reduce the safety factor of the spars by 15 per cent.

In the fourth general type the stresses in the struts and wires are transferred to the spars by means of horizontal bolts in the spars. A good example of this type of construction is to be found in the Thomas-Morse MB-6; a photograph of this fitting will be found in Figure 11. A horizontal bolt at the neutral axis of the spar carries lugs for the flying wires and has an eye-forked head for the drag-strut connection. This bolt passes through plates on the sides of the spar which extend along the spar and are fastened to it by means of six additional bolts or rivets. Rivets are used in each case at all holes but the two at which there are bolts to receive the drag-wire lugs. The plates help somewhat in distributing the stresses in the spar due to the concentrated loads from the wires and struts. The interplane strut socket has pieces that straddle the spar and eyes formed in them fit over the horizontal bolt. This fitting is light in weight, is easily assembled on the spar, would be easily replaced, and eliminates all serious eccentric stresses except in reversed flight. As there is but one landing wire which is attached at one end of the horizontal bolt, a considerable eccentric moment is developed in reversed flight in the direction of the least moment of inertia of the spar. The use of rivets is a bad feature, as driving the rivets tends to enlarge the holes and thus to weaken the spar.

The Orenco PW-3 fitting (fig. 12), and the Dayton-Wright TA-3 fitting (fig. 13), furnish additional examples of this type of design. It is recommended that when the wires are attached to one horizontal bolt, which must transmit the entire load to the spar, plates with additional small bolts be used, so as to avoid extreme concentrations of stress on the wood fiber. This is especially important in thick wing sections with thin spars. The GA-1 fitting (fig. 14) is a good example in that respect, though the wing section is not especially thick. The fitting is well designed so that there are no eccentricities, and a number of small bolts tend to distribute the stresses in the spar. In using bolts in this manner, the designer should make certain that the bolts are placed as far from the flanges of the spar as possible. These fittings are very light, easily assembled, and are easily replaced.

The fittings on the TP-1, an airplane being designed at McCook Field, are excellent examples of this type of construction. Sketches of them will be found in Figures 24 and 25. The fittings are light in weight, easily installed or replaced, and have no eccentricities. The horizontal bolts are arranged so as to distribute the stresses in the spar, and straps over the top of the spar relieve the bearing stresses of the bolts on the spar fiber.

The fitting on the Loening monoplane, shown in Figures 18 and 19, is a modification of this type. Plates bolted to the sides of the spar extend over the upper flange in the form of a yoke and have extensions on the lower side of the wing, in which eyes are formed to receive the hinge pin of the strut connection. This design would be very satisfactory if the bolts were not placed so near the flanges of the spar and were more uniformly distributed. The U-shaped or strap fitting as used on the Fokker D-7 and the PW-1A is shown in Figures 15, 16, and 17. It will be observed that the horizontal bolts are kept well away from the flanges. These fittings are very light, easily made, and easily placed in position on the spar.

STRUT FITTINGS.

There has been a great variety of interplane strut fittings, though most of them are of the ball-and-socket or hinged types, differing only in minor details. In general these types are very satisfactory, as they are light in weight and are easily assembled or disassembled. As a rule, the pin should be parallel to the spar, as this gives the greatest degree of fixity of the strut ends in the direction of the least moment of inertia of the strut. (See fig. 20.) With the pin parallel to the spar it is possible to change the stagger of the wings readily, which is an advantage in experimental work, or where a new design is being brought out. In airplanes with internally braced wings or with continuous spars the interplane struts may carry either compressive or tensile stresses, and the fittings should be designed accordingly. This is also true of the lift struts on monoplanes and of the cabane or center section struts on most airplanes.

The fitting is generally attached to wood struts by means of a socket or shoe which fits the end of the strut and is held in place by a pin, a bolt, or by wood screws. Figures 1, 2, 5, 7, and 11 illustrate this type of connection, which is light, easily installed, and has proven to be very satisfactory. The arrangement shown in Figure 12 does not distribute the stresses throughout the material at the ends of the strut and tends to split the strut. In the case of metal struts either a socket or a plug may be used. Plugs should be riveted and brazed to the strut, but in many cases it is satisfactory to weld the sockets in place or even to rivet and solder them. The plug or socket has a suitable recess or head to complete the connection with the spar fitting. This may be a socket to fit over an eye, fork, or ball head on a bolt or plate, or an eye to complete a hinge joint, or a ball to complete a ball-and-socket joint. Some of the different methods are shown in Figures 6, 9, 13, 15, 19, and 20.

When the strut connection is made to a suitable head brazed to a lug plate which is bolted to the spar, as shown in Figure 6, or to a strap fitting which slips over the spar, as shown in Figures 12, 15, and 17, careful design will prevent any serious eccentricities. If the interplane struts slant so as to form an acute angle with the longitudinal axis of the spar, the strut fitting may be arranged as shown in Figure 13, so as to prevent serious eccentric stresses. On the DH-4 and the TW-1 the struts were attached directly to the bolts as shown in Figures 1, 2, and 9. The DH-4 arrangement was faulty, inasmuch as the bolt passed vertically through the spar. Otherwise this method is as satisfactory as the one in which the attachment is to a head brazed onto a plate. However, in most cases it is easier to prevent eccentricities when plates are used.

When the spar fitting is of the box type, the side pieces may be extended beyond the spar and formed into lugs, or lugs may be brazed to the sides of the fitting. A pin through these lugs, together with a suitable fitting on the strut, completes the connection. The GA-1 furnishes a good example of this type of construction. The connec-

tion is light and easily made, but it would be more satisfactory if the lugs were brazed to the fitting so that the pin would be parallel to the spar.

In the Thomas-Morse MB-3 and MB-6 the strut socket has side pieces that straddle the spar and are attached to it by means of a horizontal bolt, as shown in Figure 11. This arrangement is light, does not cause eccentric stresses, and is easily installed. However, it is not as readily disassembled as some of the other types, the least degree of fixity is in the direction of the least moment of inertia of the strut, and the strut length is increased.

A more rigid type of connection was used on the Salmson 2A2 and the Lepere U. S. A. C-11. The Salmson 2A2 fitting consists of a socket brazed to a box-spar fitting, into which the end of the wood strut is fitted. The end of the strut is tapered to such an extent that the degree of fixity is not materially increased beyond a coefficient of 1, and the fitting is of a type that is not easily assembled or replaced on the spar. For the Lepere connection steel plates bent into the form of a J are bolted to the sides of the picture-frame strut. Vertical bolts through these pieces straddle the spar and are held in place by a tie-plate on the opposite flange of the spar and by the drag-strut fitting. This arrangement is light, gives a good degree of fixity, and is easily installed or replaced. A sketch of the Lepere strut fitting will be found in Figure 23.

Considerable work has been done on designs for adjustable interplane struts and one or two excellent designs have been completed. Adjustable struts have many desirable features when installed on experimental airplanes, but they are heavier and more difficult to construct and there is no apparent reason why they should be used on standard designs.

LIFT WIRES.

Standard stream-lined wire or steel-wire cable is generally used for the flying and landing wires. The stream-lined wires are attached to the lugs by means of universal ends which consist of a clevis and trunnion, as shown in Figures 1, 11, and 12. The clevis fits over the lug to which it is secured by a pin or bolt, and the trunnion receives the threaded end of the wire, which is fixed in position by a lock nut. Or the clevis may be formed into a lug itself, as on the Thomas-Morse MB-6 (fig. 11). The wires should never be secured at the ends, as shown in Figure 20, as the universal ends are necessary to allow for the vibration of the wings. The wire cables are attached to a lug at one end by means of a clevis and to a turnbuckle at the other. This permits the tension in the wires to be adjusted easily. The cable is bent over a thimble and spliced to form an eye in the end. The eye is attached to the lug by means of a clevis or the eye is spliced to include the adjustable end of the turnbuckle. The splice should be wrapped with fine wire and soldered. Cable connections are shown in Figures 2, 3, 5, 6, 7, and 13. Stream-lined wire is much more satisfactory than steel-wire cable, as it will not stretch, is easier to install, and has considerably less wind resistance. However, steel-wire cable has a certain advantage in ease of manufacture, as the stream-lined wires must be made special for each length required, while the cables can be cut and spliced to suit.

The flying and landing wires are attached to the spar by means of bolts in the spar, by means of lugs formed in lug plates, or by means of lugs brazed to box or strap fittings. The fitting should be designed to develop the full strength of the wire without failure. Care should be exercised in the design to eliminate wind resistance and eccentricities. A small eccentricity in a wire connection might easily cause a moment great enough to decrease the safety factor of the spar as much as 15 or 20 per cent.

The Thomas-Morse MB-6 (fig. 11) furnishes a good example of the design with the wires attached directly to a horizontal bolt in the spar. As the bolt is at the neutral axis of the spar and on line with the interplane strut, no eccentricity is developed. However, in reversed flight considerable eccentricity is developed in the direction of the least moment of inertia of the spar, due to the fact that there is but one landing wire in each bay of each truss and that it is attached to but one end of the horizontal bolt. Otherwise this design is very good. Other good examples of this type of design will be found on the Orenco PW-3, shown in Figure 12, on the Dayton-Wright TA-3, shown in Figure 13, and on the TP-1, Figure 24. The flying or landing wires should not be attached directly to the ends of vertical bolts, as this arrangement will generally cause serious eccentricities in the spar.

When lugs are brazed to a box fitting or formed in the extended sides of the fitting, as shown in the Salmson 2A2 or the GA-1, it is easy to arrange them so that the wire tensions will not cause eccentricities. This type of fitting is satisfactory in many ways, though it is heavier than many of the other types and is rather difficult to install on the spar. Figure 14 shows a wire fitting for one of the intermediate wing spars of the GA-1. It is light, easily made, readily replaced, and would have no serious eccentricities unless the wings had considerable stagger.

More often the wires are attached to the spars by means of lug plates which are bolted to the spar. A lug plate is a piece of sheet metal which is bent up at the ends to form eyes or lugs. The plate may be attached to the spar by vertical bolts in the spar as on the Vought VE-7 and the DH-4, or it may be attached by means of vertical bolts that straddle the spar as on the Lepere, the Curtiss JN-4, and the Orenco C and D. Using vertical bolts in the spar weakens it materially. Figures 1, 2, and 3 show this method of attachment. The use of lug plates with bolts that straddle the spar, as shown in Figures 5, 6, and 7, is generally quite satisfactory, as this type of fitting is light in weight, easily made, and is easily installed or replaced on the wings. Furthermore, careful design should eliminate all serious eccentricities, though the use of two bolts, as shown in Figure 9, will generally increase them. Figure 21 illustrates the results of a failure due to eccentric stresses. The flying wires were attached to the lower bolts in the compression rib and the eccentric moment set up about the longitudinal axis of the rib caused failure of the rib fitting.

INCIDENCE WIRES.

Incidence wires are generally fastened to the spars by means of lug plates or to the interplane strut socket by means of lugs or posts brazed onto the metal end piece or formed in it. These methods are shown in Figures

1, 2, 3, 5, 6, 7, 11, and 20. When attached to the strut socket, eccentricities may be induced, but they will be small and are in the direction of the greatest moment of inertia of the strut. In general these types are light in weight, easily assembled, and are satisfactory in every way.

In some instances the incidence wires have been attached directly to an eyebolt which acts as one of the spar fitting bolts. This arrangement was used on the XB-1A and is satisfactory when the spar fitting has but two vertical bolts which are in the line of the interplane struts.

In the Vought VE-7 the incidence wires are attached to a lug plate which is let into the strut itself, splitting the strut at one end along the major axis of its cross section, and pin connected to the strut and strut socket. This type of construction is not so desirable, as it weakens the strut somewhat and is more difficult to manufacture.

INTERNAL DRAG STRUTS.

Compression ribs or drag struts made of wood are generally attached to the spars by running the cap strips over the spars and fastening them to the spars by means of glue and nails. The end of the rib is glued to the sides of the spar and the joint is strengthened by triangular blocks glued and nailed to the rib and to the spar. This method gives an extremely light joint and is satisfactory in every way. However, care should be exercised so that the strut will have an even, firm seat on the spar. This type of drag strut and its end connection is shown in Figures 2 and 19. When the wood drag strut does not also act as a former rib it may be bolted to the drag-wire lug plate, as shown in Figures 6 and 24. This type of strut is easily built, the end connections are simple and easily made and installed, and the ultimate strength of the strut can be computed with considerably more exactness than the built-up type of strut shown in Figure 2.

Metal struts are generally made with plugs in the ends which are bolted to suitable fork or eye heads on a horizontal bolt through the spar or on a plate which is bolted to the spar. If a plate is used, a suitable head is brazed to the plate and the ends of the plate are turned up and formed into lugs which receive the drag wires. These types are shown in Figures 3, 8, 11, and 22. They give a light, firm joint, which is quite essential for drag truss members, as they can not be inspected once the wing is completed without removing the fabric. However, the degree of fixity of the strut ends is very low. The arrangement of the drag-strut connections on the CO-2 is much more satisfactory in this respect, as angles are riveted to the tubes or metal boxes which are used as struts and then bolted to the spars. This gives a much better degree of fixity and a lighter strut may be used. The horizontal bolts through the spar should be placed close together so as to weaken the spar as little as possible.

A special case is furnished by the VCP-1. (See fig. 21.) The compression rib at the outer strut is attached to the spars by means of a piece of sheet metal bent to form a yoke that fits over the rib and is bolted to it and with the ends bent up to form angles which are bolted to the spars. This gives a rather heavy fitting, but the degree of fixity of the strut ends is high and the heavy fitting is necessary because the I-strut is attached to the center of the compression rib between the spars, and the rib must carry heavy bending loads as well as compressive stresses.

INTERNAL DRAG WIRES.

The drag wires are attached either to lugs which are brazed to box spar fittings or to lug plates which are bolted to the sides of the spar by two or more bolts. The bolts should be placed at or near the neutral axis of the spar so as to effect its moment of inertia as little as possible. On the outer side of the spar a good-sized washer or plate should be used with the bolts, as shown in Figure 22, so as to prevent crushing of the wood. These types give light, firm joints and are satisfactory in every way.

In the older designs steel wire was used for the drag wires. A turnbuckle was placed at one end for ease in adjustment of the initial tension in the wire and the joint was accomplished by threading the wire through the eye or lug and serving it, as shown in Figures 5, 6, 7, and 19. In the more modern designs swaged tie-rods are used, as they will not stretch as easily as the steel wire, which is quite important for drag-truss members. The tie-rods are connected to the lugs by means of clevis ends, as shown in Figures 2, 8, 9, 11, 21, and 22.

WING COUPLINGS.

Where wings are hinged at the fuselage or center section, a hinge coupling with the pin horizontal is the best arrangement, as it allows changes in the dihedral angle, does not interfere with the deflection of the wings, and is easy to mount or dismount. The fitting should consist of a shoe which fits over the end of the spar and is bolted to the spar by means of horizontal bolts. Vertical bolts weaken the spar considerably and should not be used. Suitable eyes are brazed onto the ends of the shoe which, together with the pin, complete the joint.

When a vertical pin is used to complete the connection, the fitting transmits more or less bending to the longerons or to other parts of the structure. As it is impossible to determine the amount of bending carried by the fitting in this case, it is impossible to make an exact analysis of the bending moments and stresses in the spars and adjacent structural members, because the spar is neither hinged nor continuous. When a horizontal pin is used, the spar is pin jointed at this point beyond question and the bending moments, shears, etc., in the spars may be determined with precision.

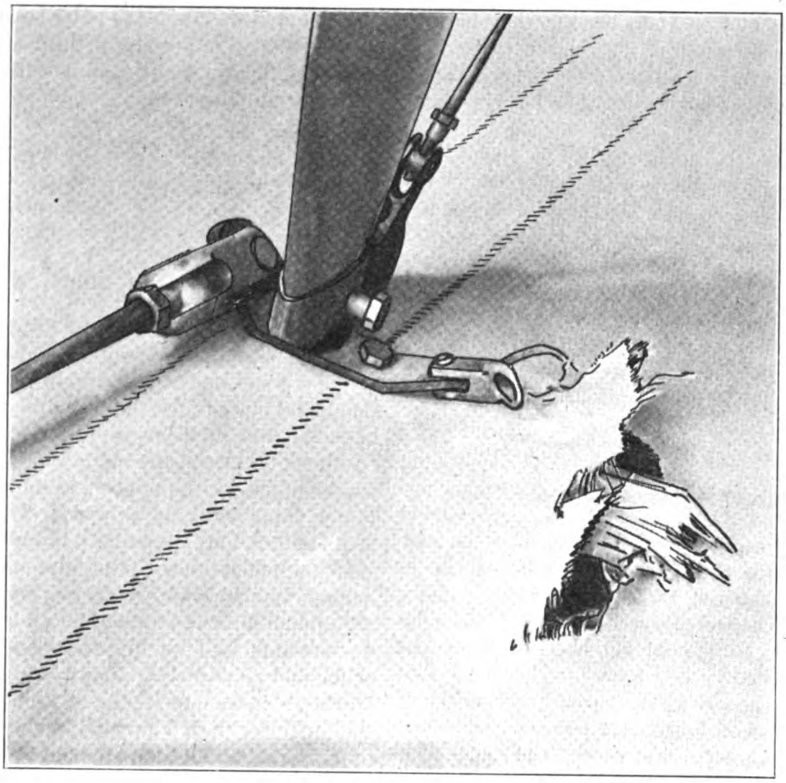


FIG. 1.—DH-9A.

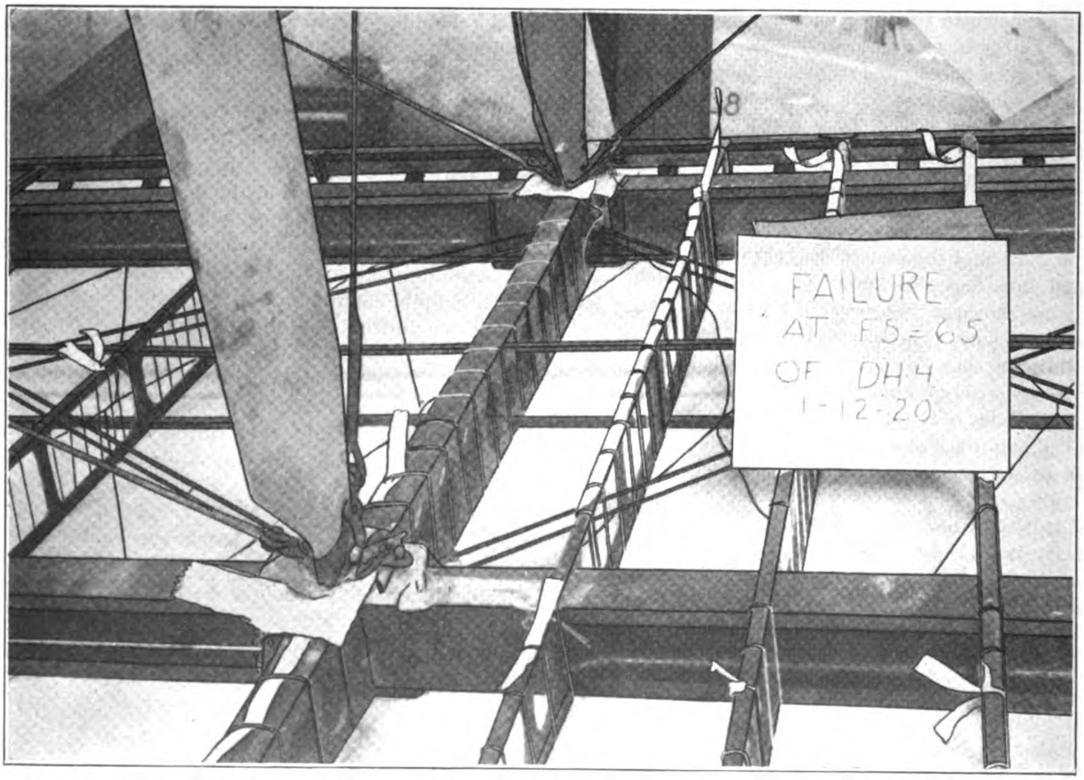


FIG. 2.—DH-4.

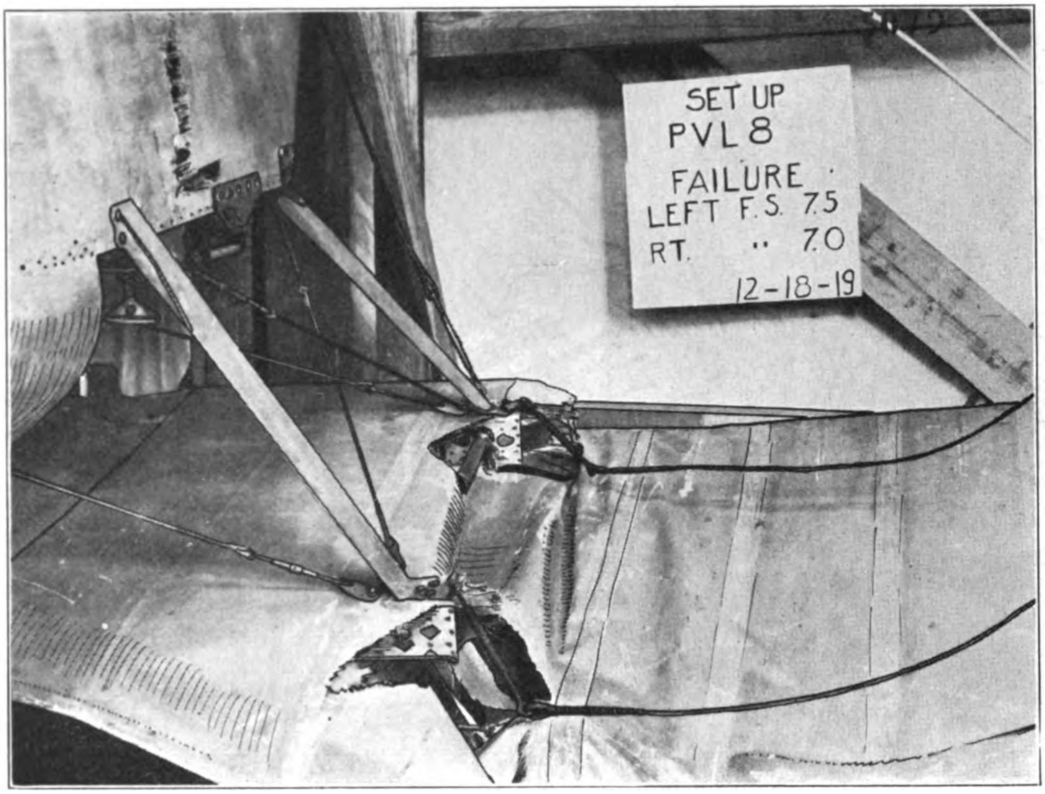


FIG. 3.—Pomilio FVL-8.

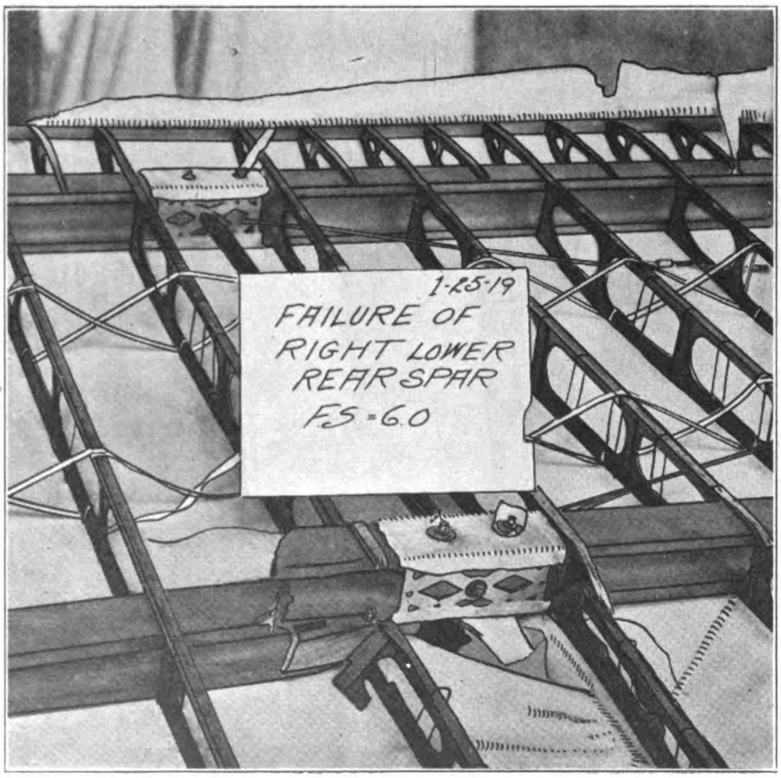


FIG. 4.—Pomilio BVL-12.

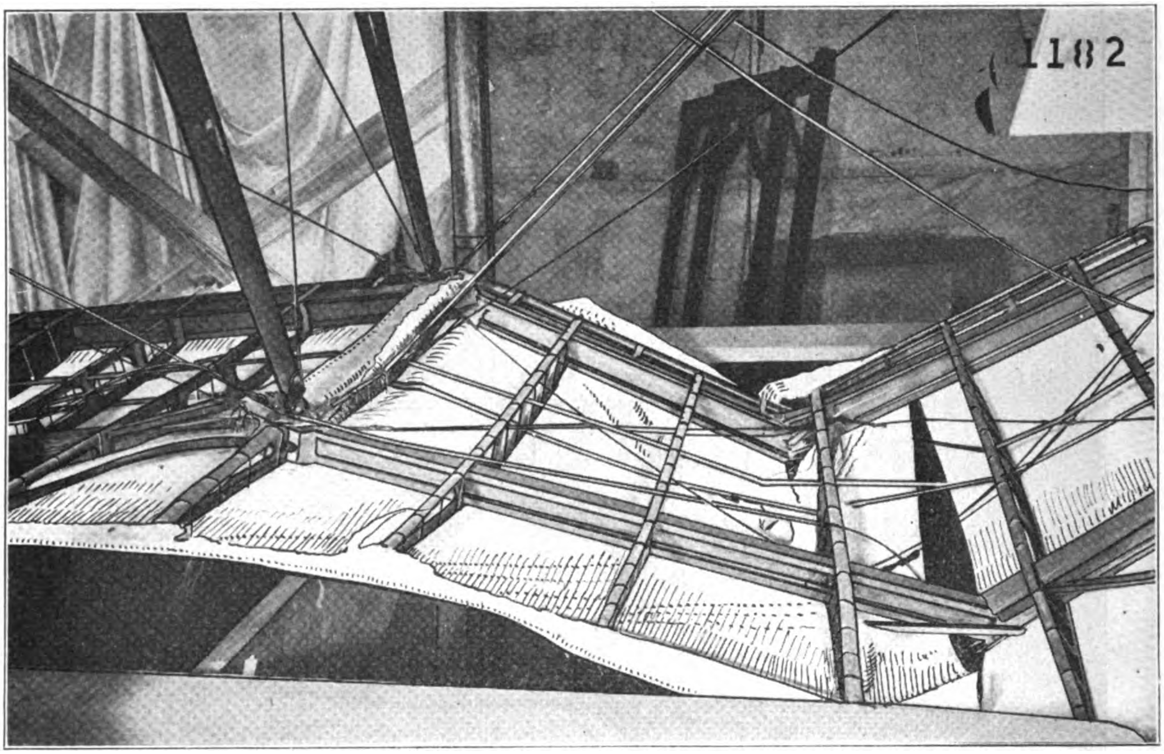


FIG. 5.—JN-4.

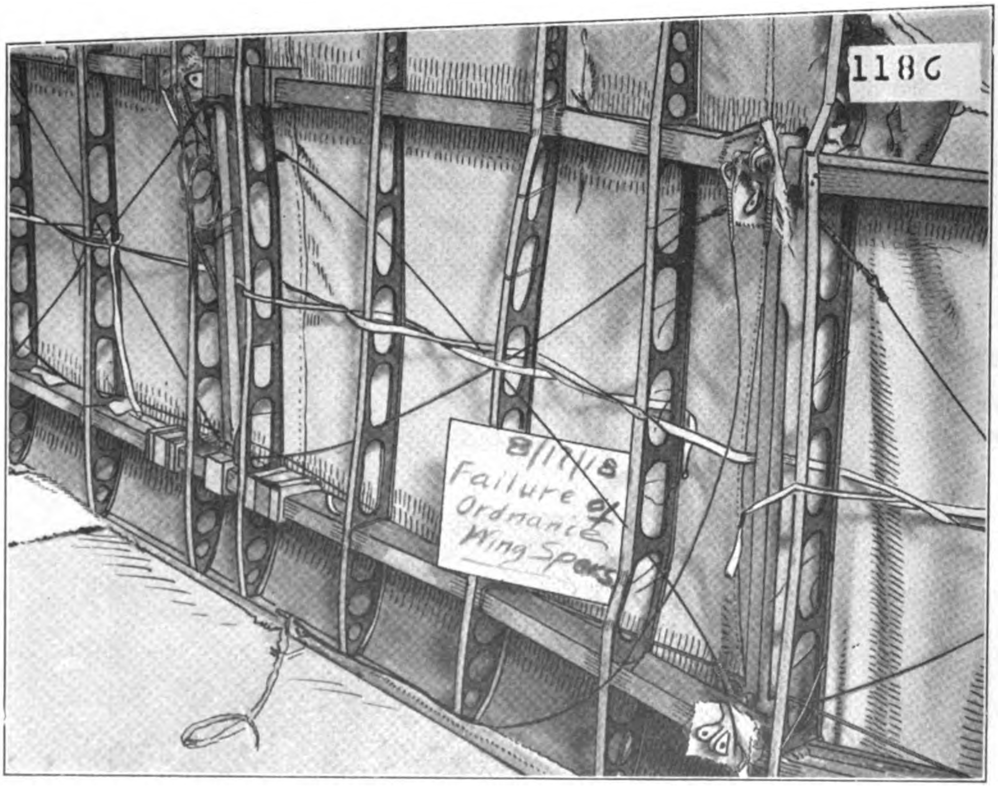


FIG. 6. Orenco-C.

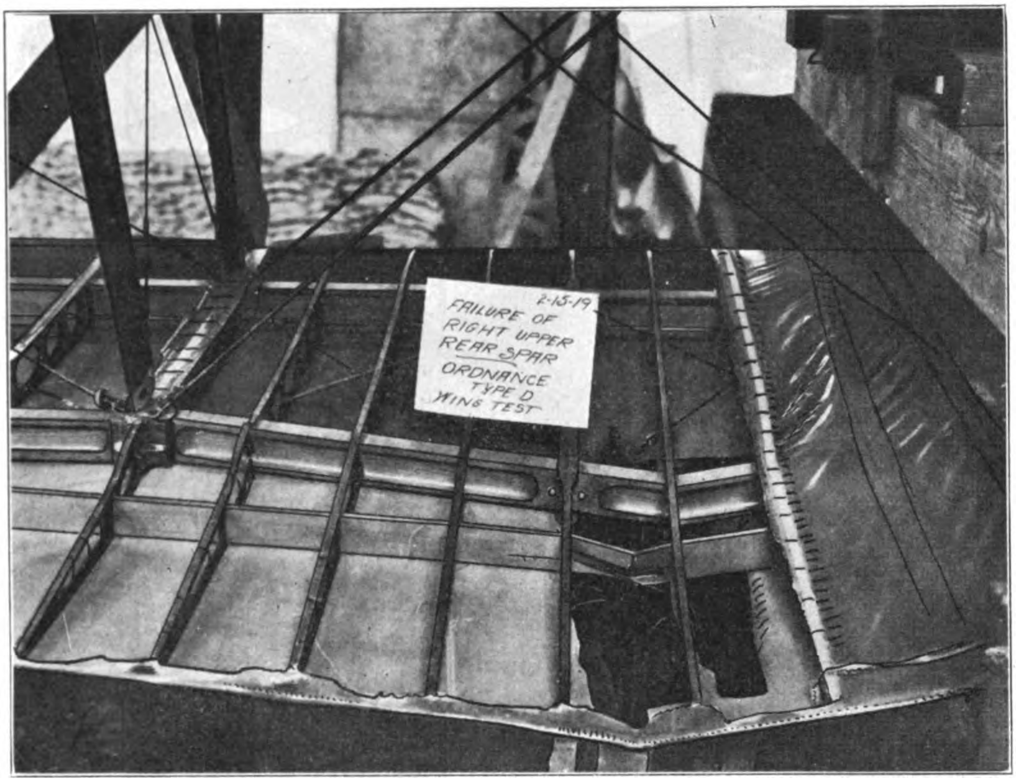


FIG. 7. Orenco-D.

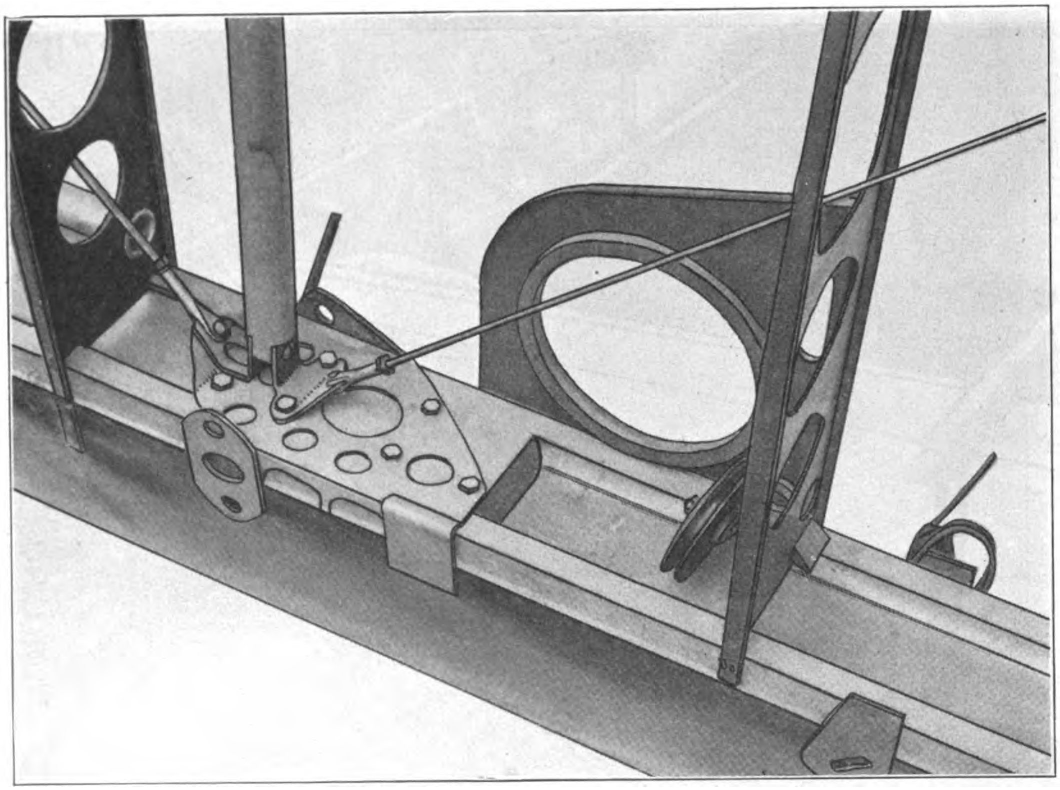


FIG. 8.—TW-1.

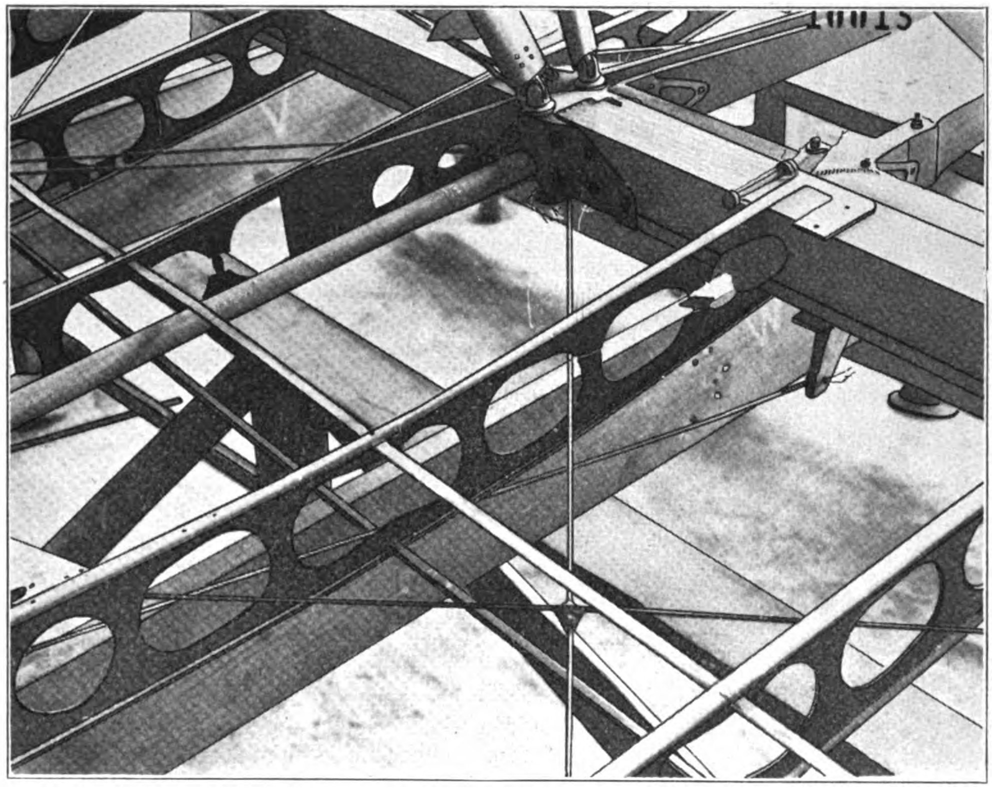


Fig. 9.—TW-1.

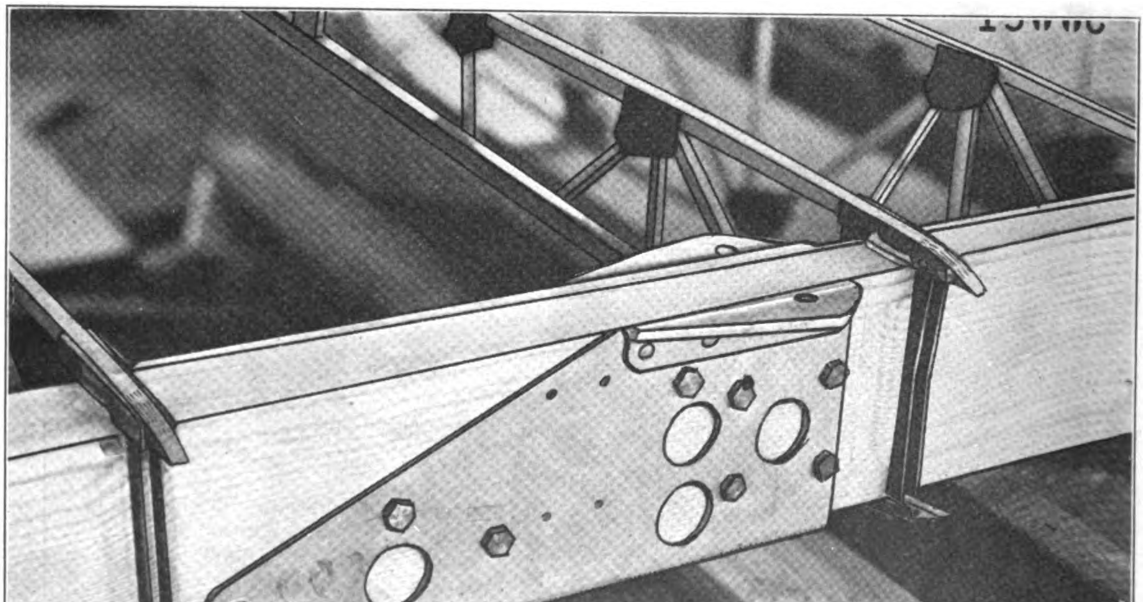


Fig. 10.—CO-2.

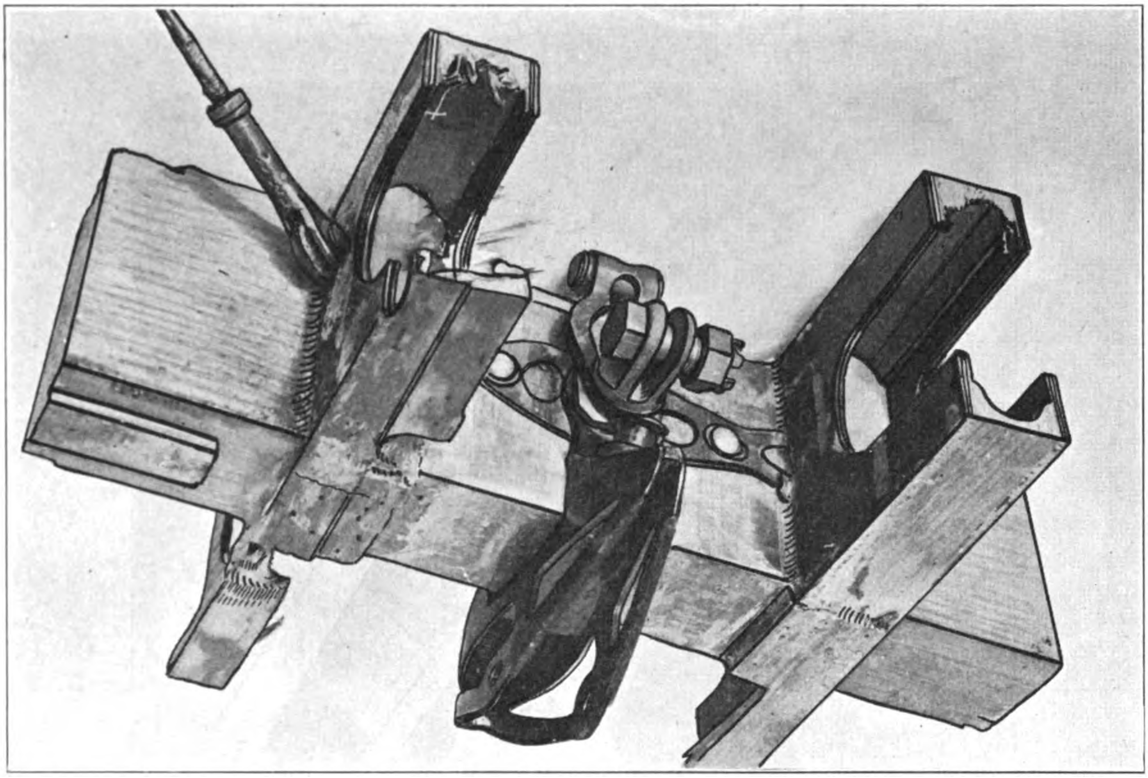


FIG. 11.—Thomas-Morse MB-6.

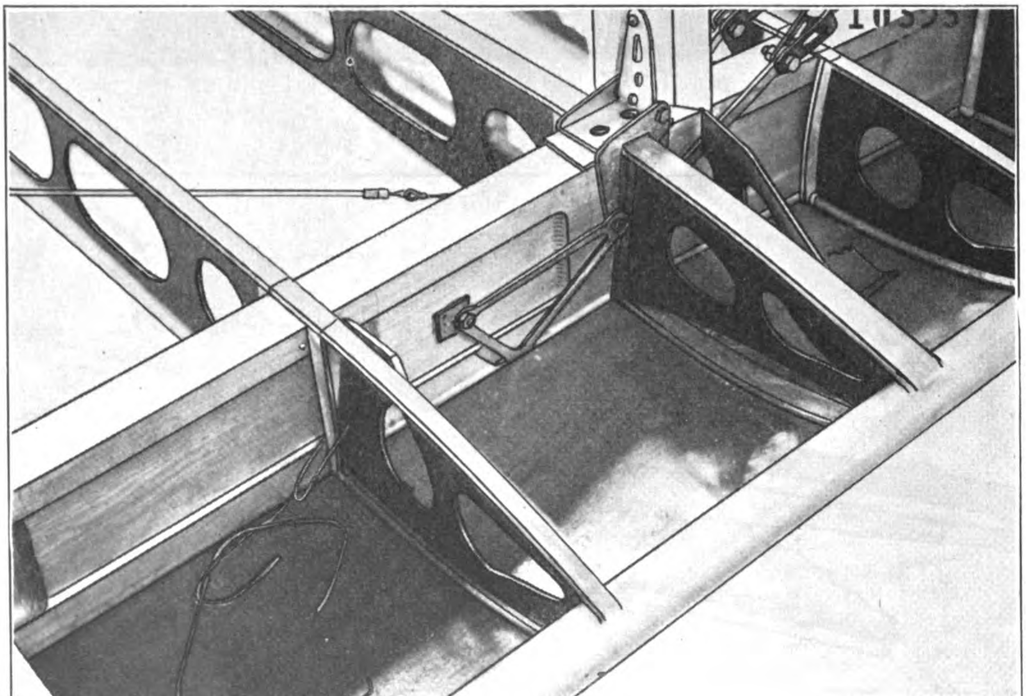


FIG. 12.—Orenco PW-3.

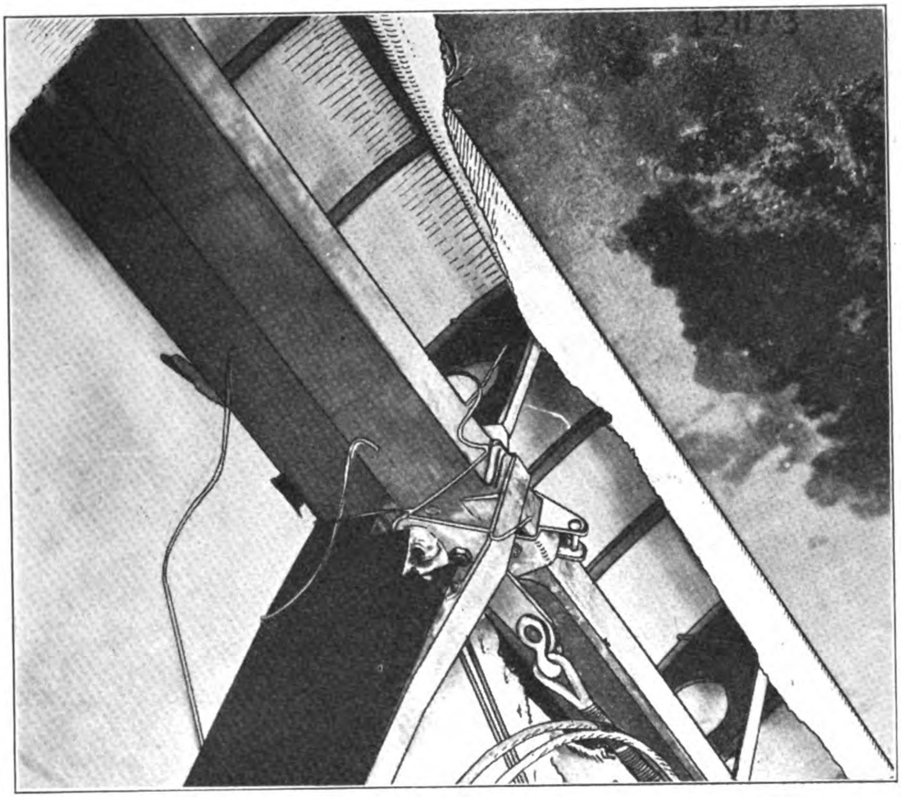


FIG. 13.—Dayton-Wright TA-3.

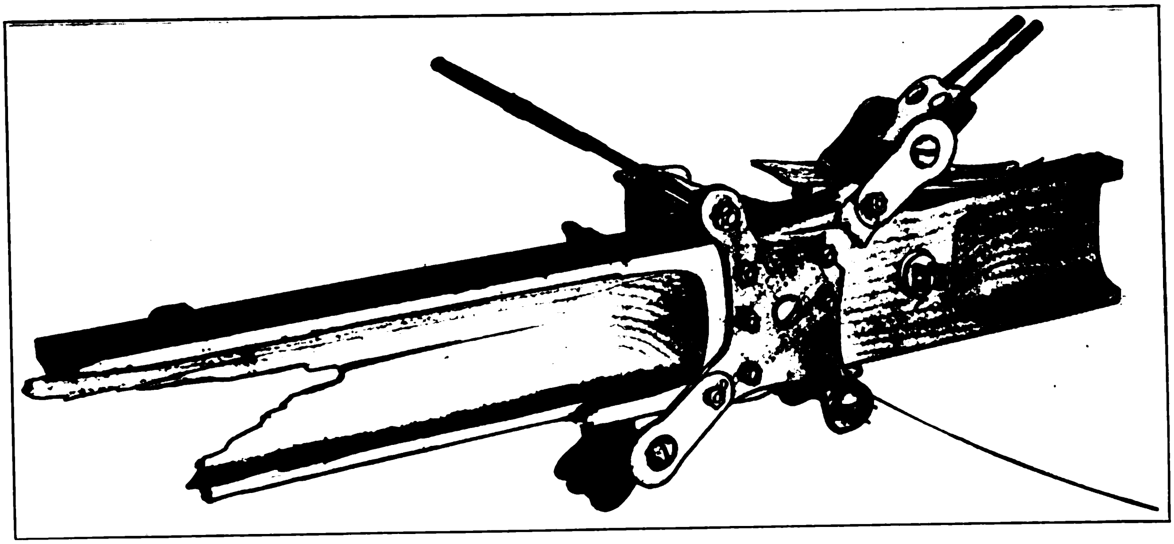


FIG. 14.—GA-1

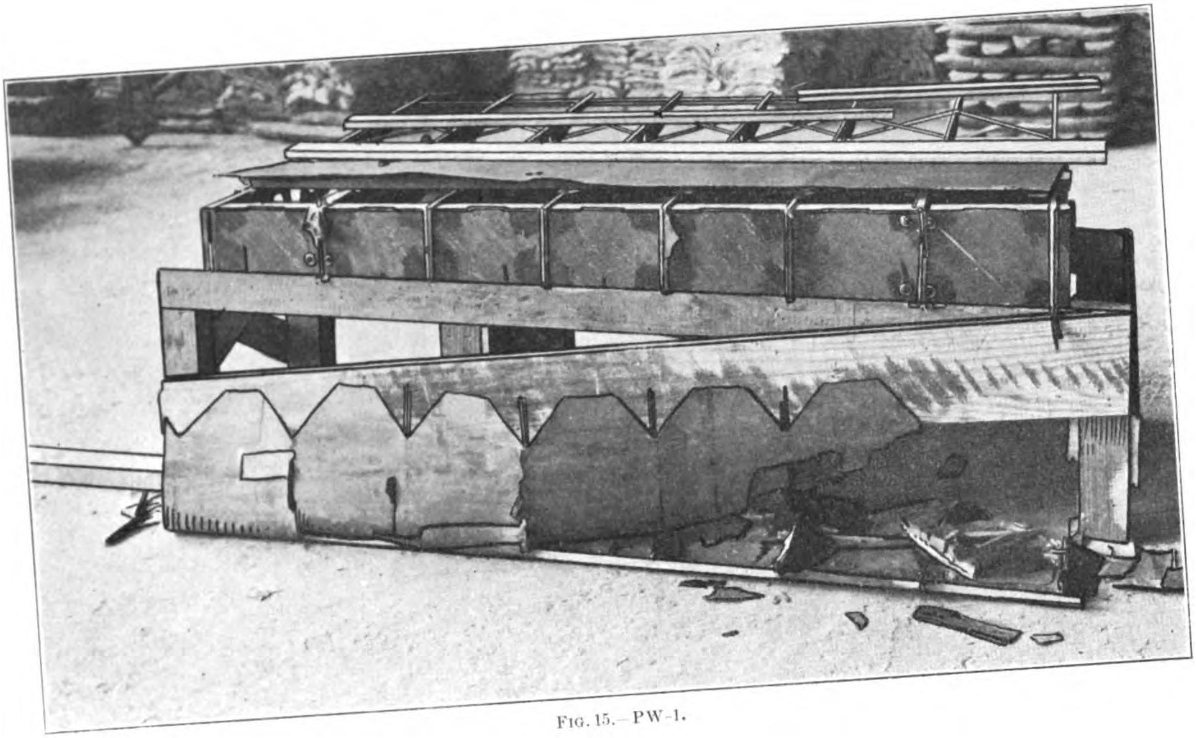


FIG. 15.—PW-1.

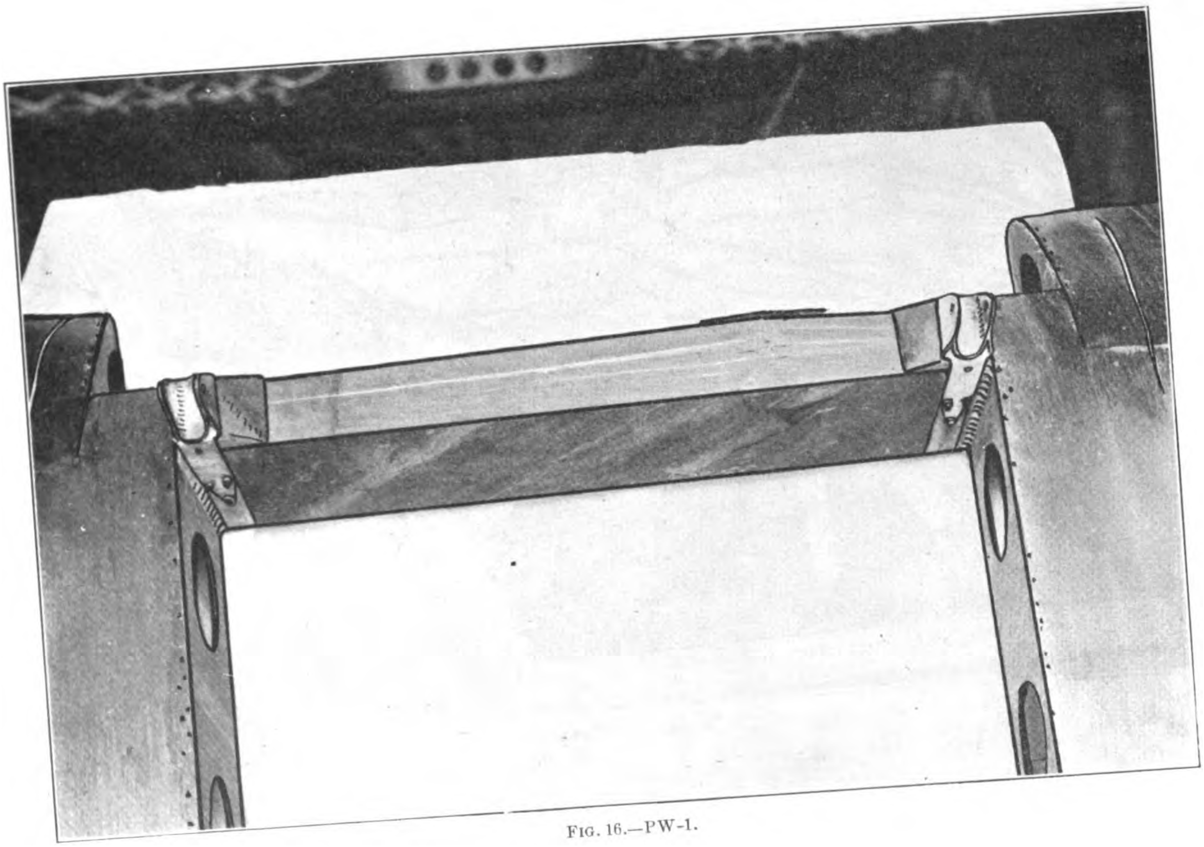


FIG. 16.—PW-1.

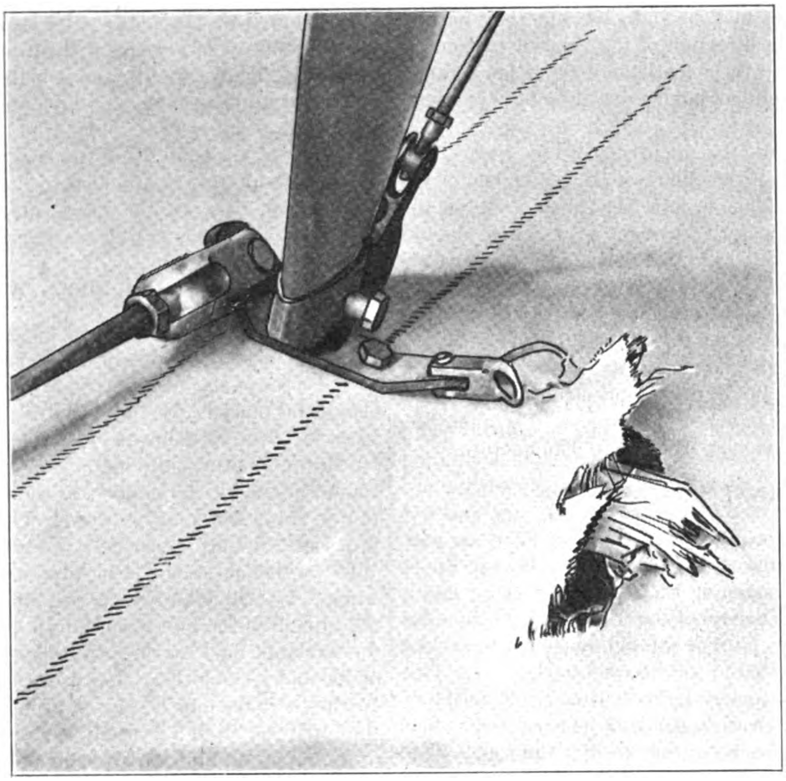


FIG. 1.—DH-9A.

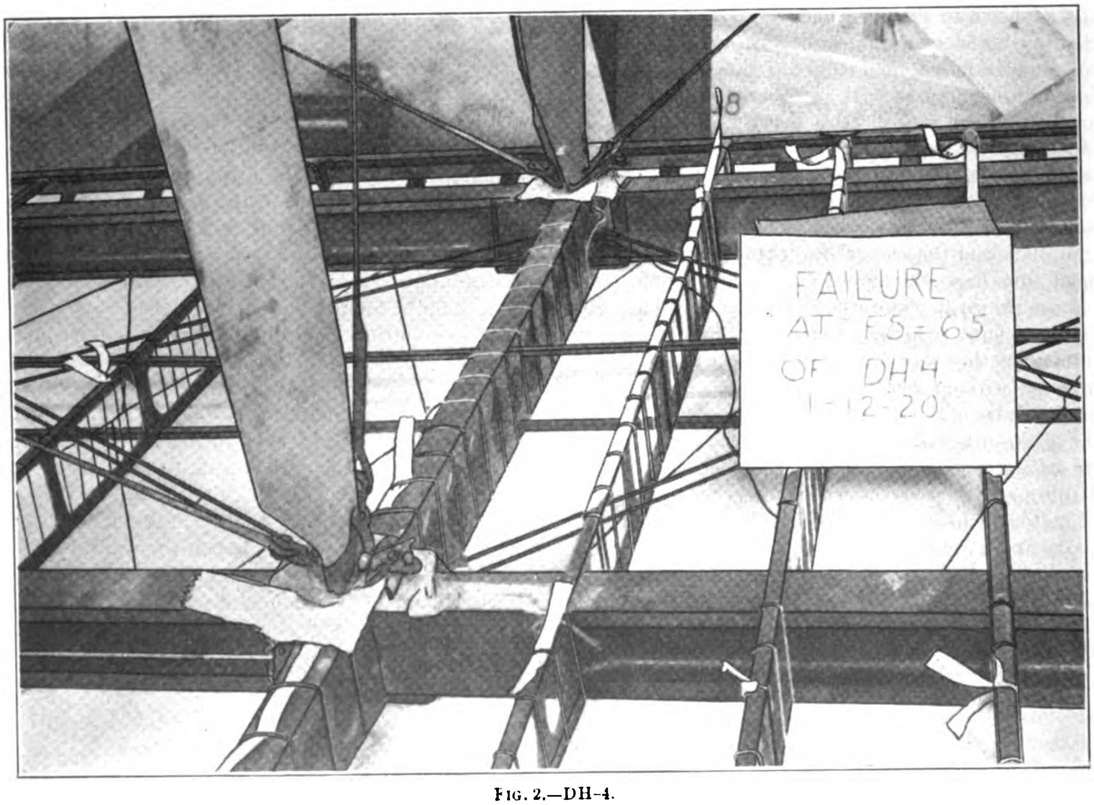


FIG. 2.—DH-4.

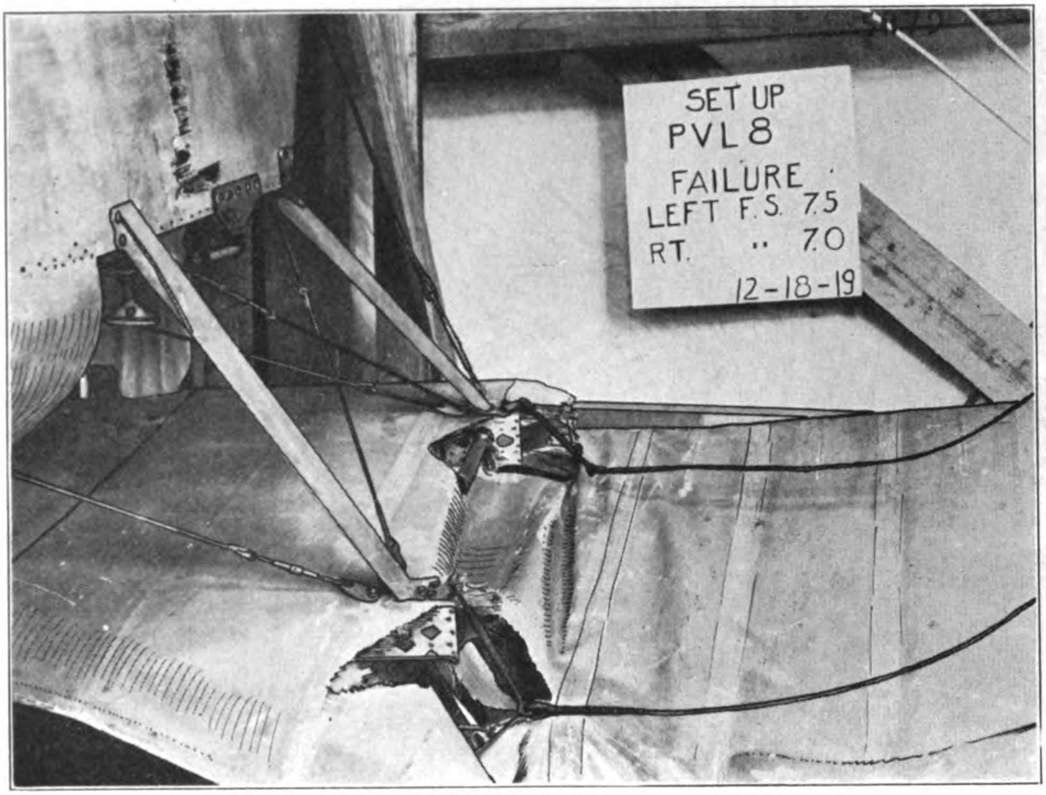


FIG. 3.—Pomilio FVL-8.

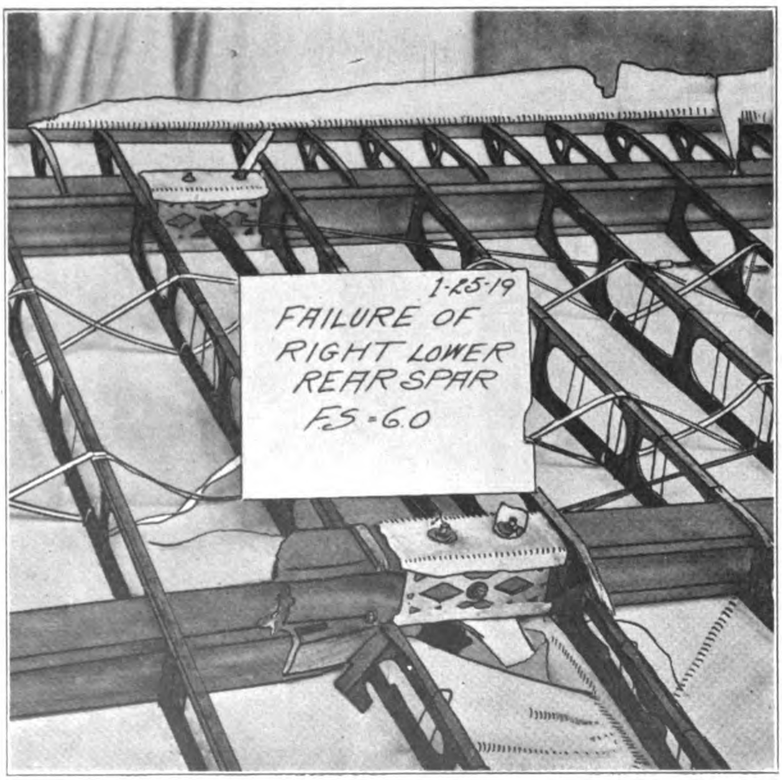


FIG. 4.—Pomilio BVL-12.

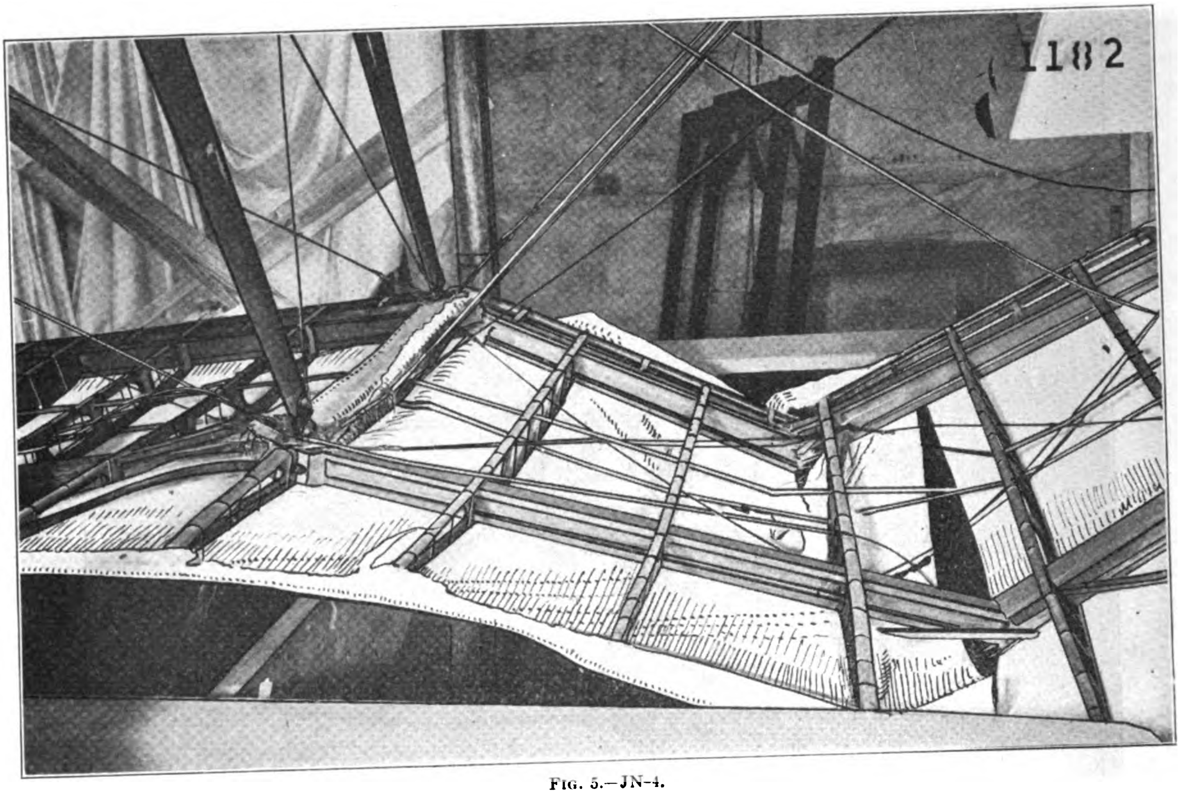


FIG. 5.—JN-4.

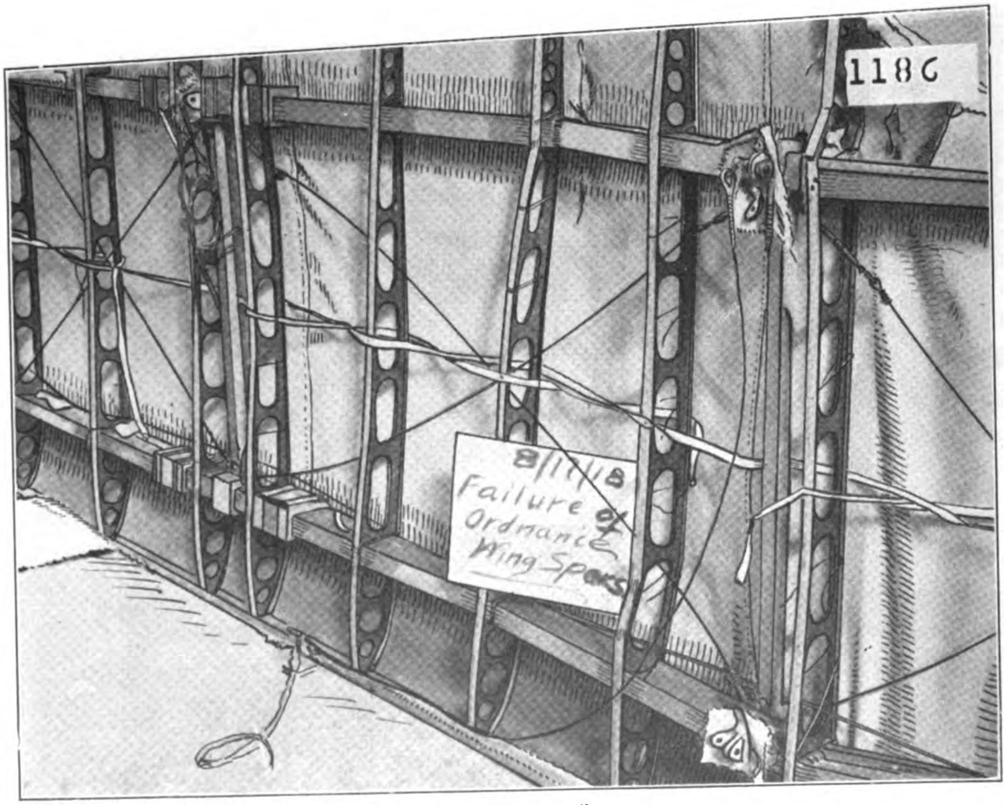


FIG. 6.—Orenco-C.

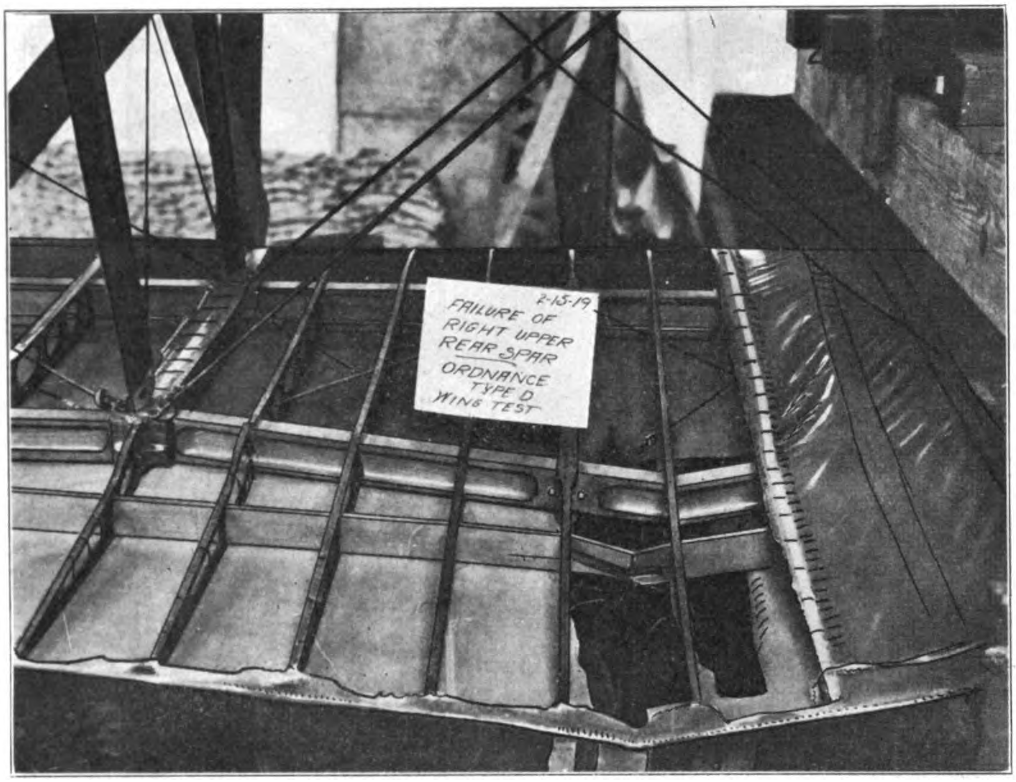


FIG. 7. Orenco-D.

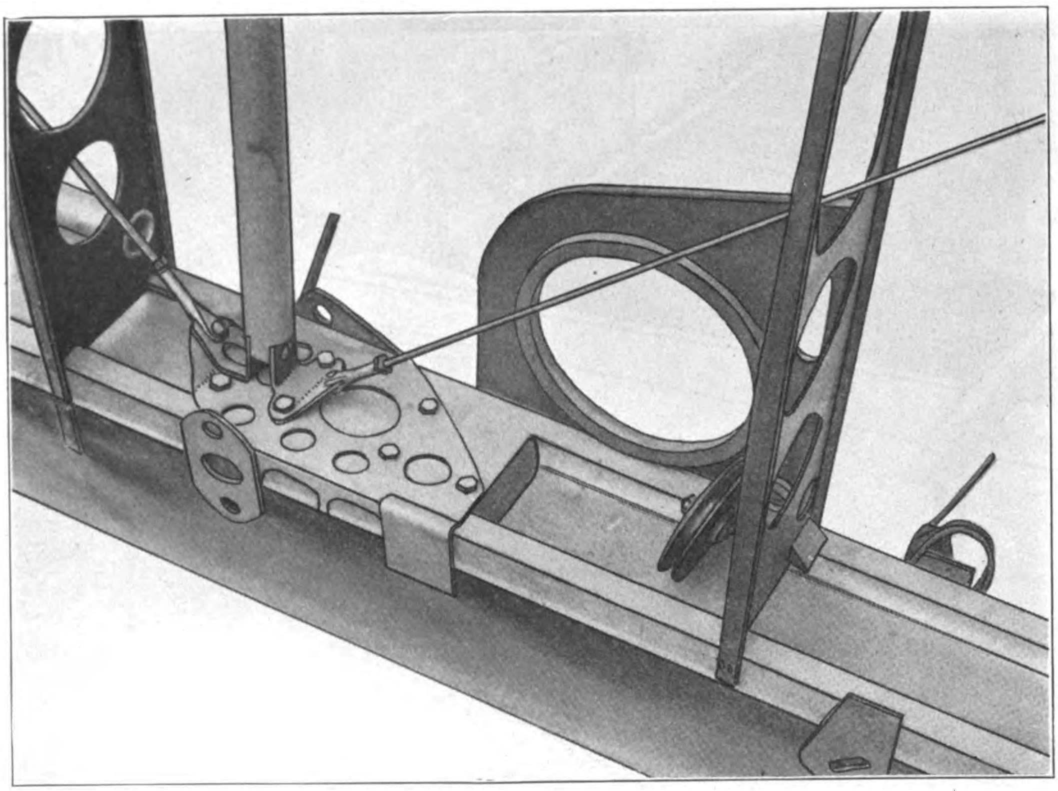


FIG. 8.—TW-1.

File D 70/64 *McCOOK FIELD REPORT, SERIAL No. 1990*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV December 1, 1922 No. 389

PYROTECHNIC PROJECTOR AND AMMUNITION SUBMITTED BY THE ORDNANCE DEPARTMENT FOR TEST

(ARMAMENT SECTION REPORT)

▽

Prepared by Charles Leigh Paulus
Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 3, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

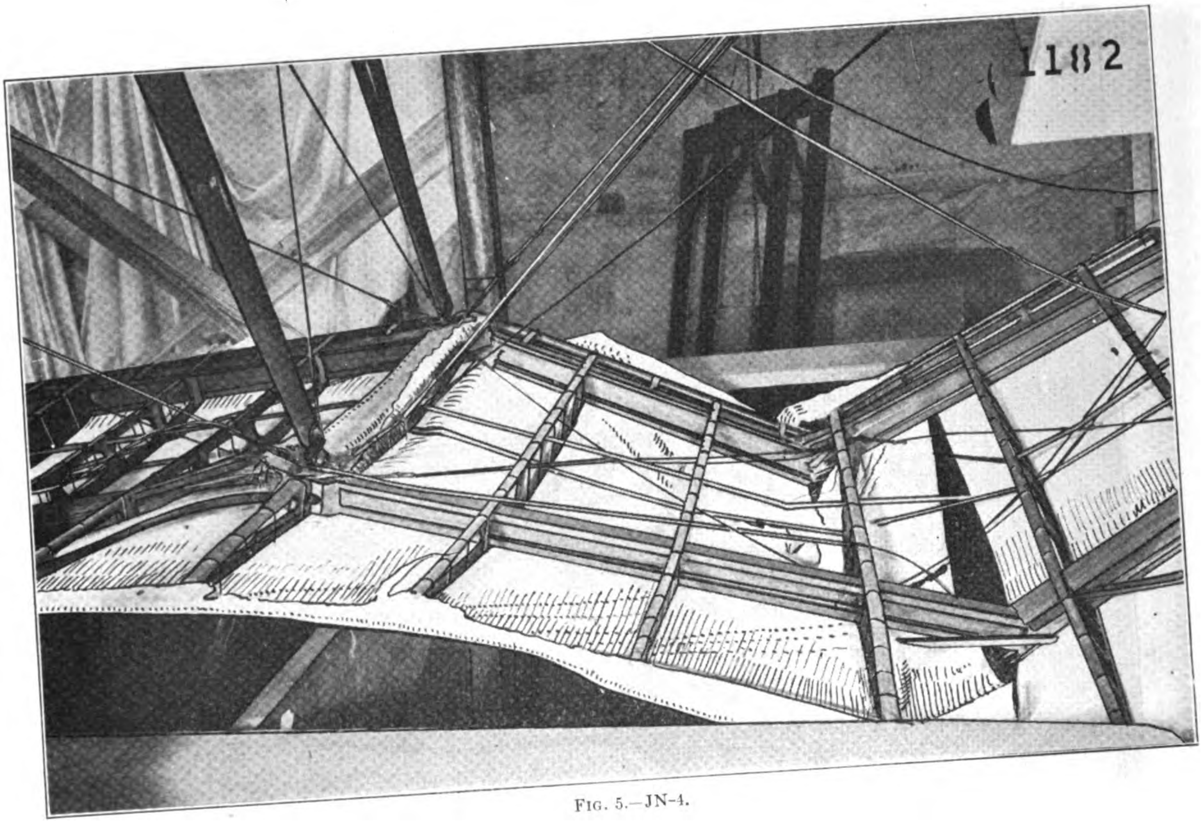


FIG. 5.—JN-4.

FIG. 6.—Orenco-C.

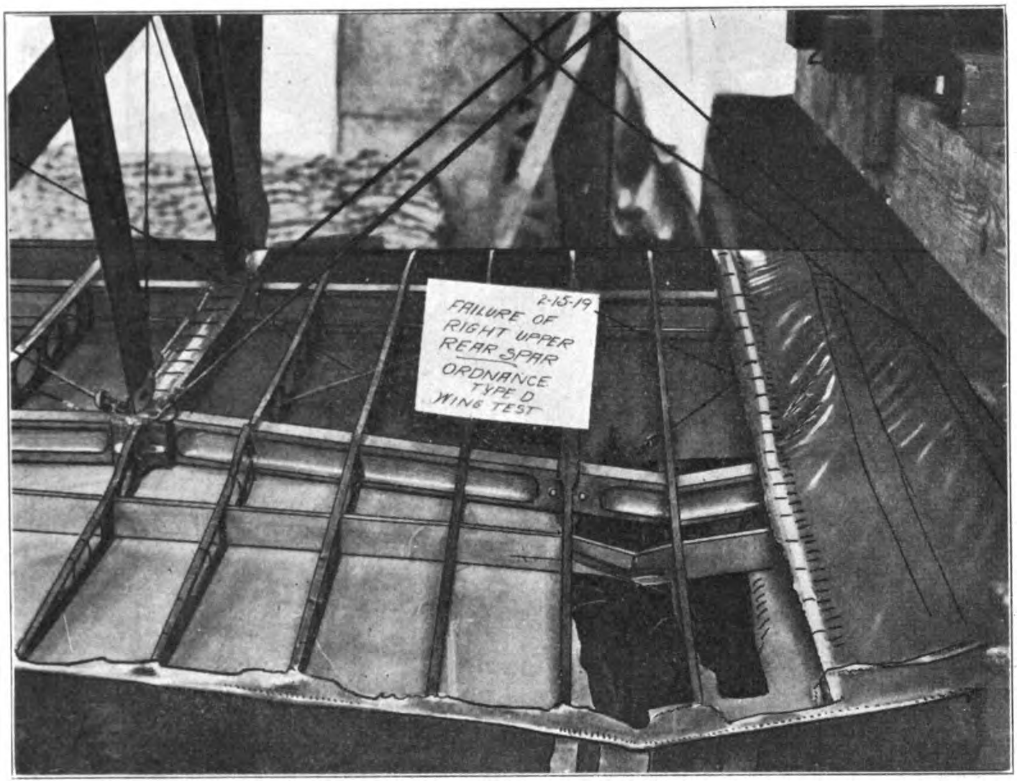


FIG. 7.—Orenco-D.

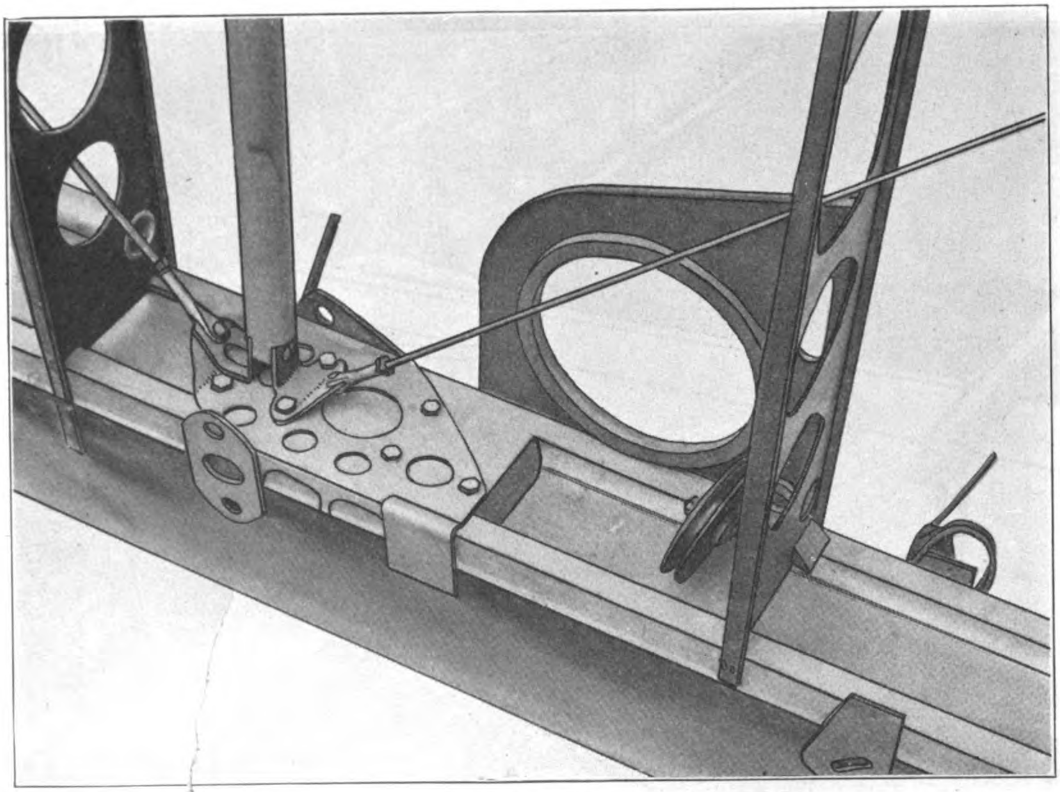


FIG. 8.—TW-1.

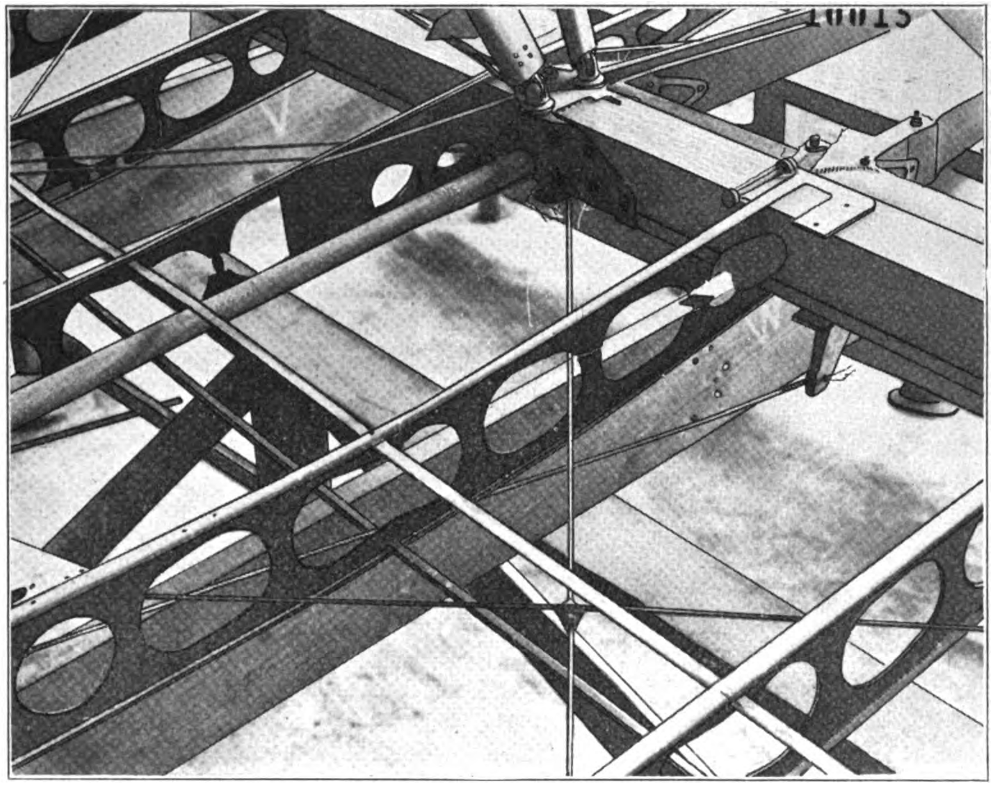


FIG. 9.—TW-1.

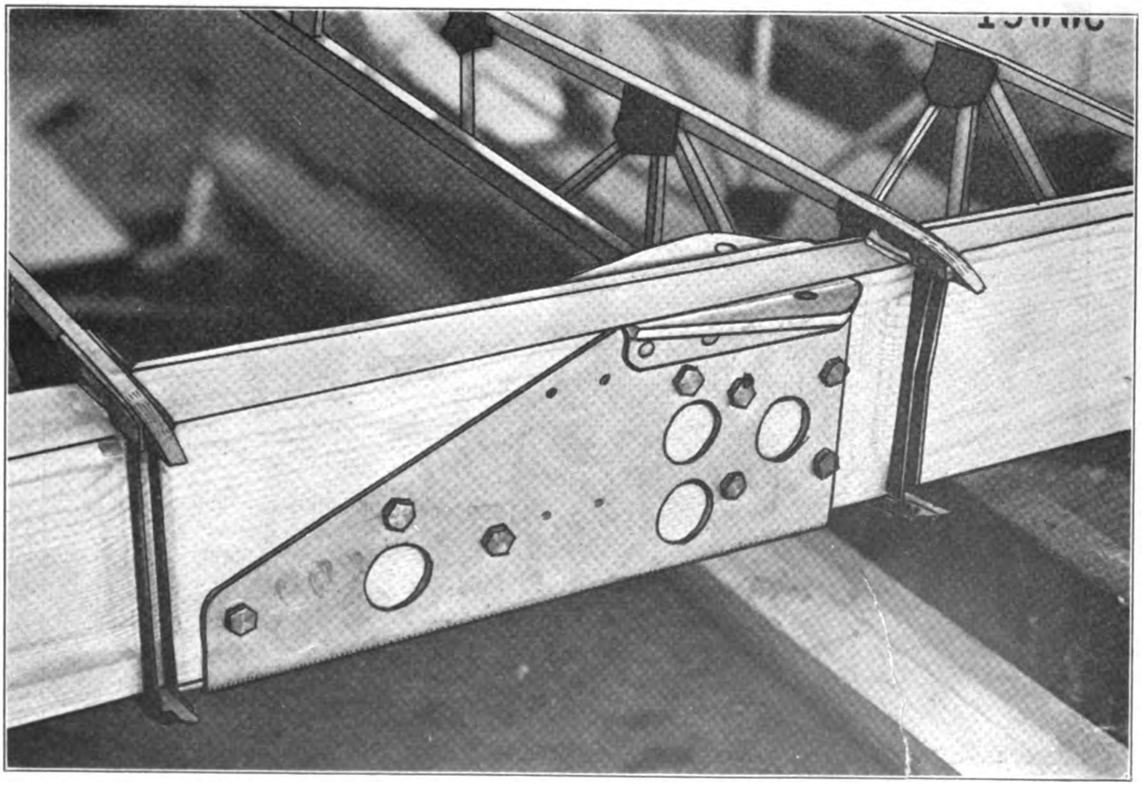


FIG. 10.—CO-2.

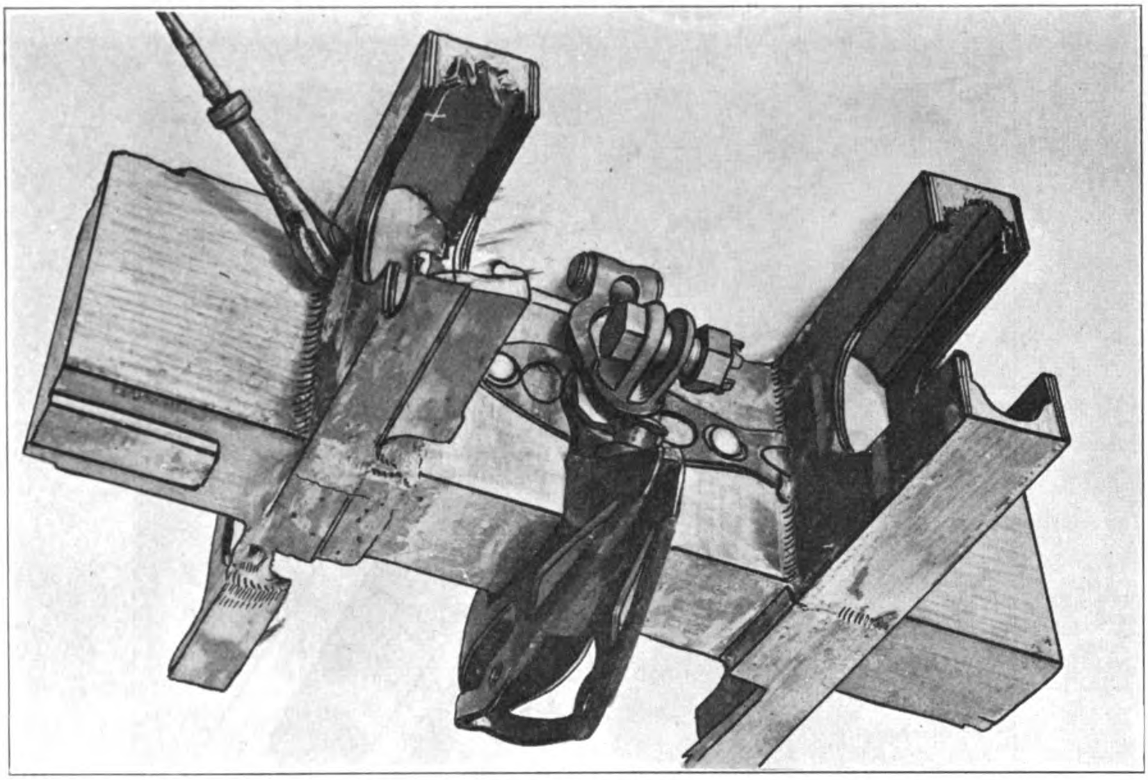


Fig. 11.—Thomas-Morse MB-6.

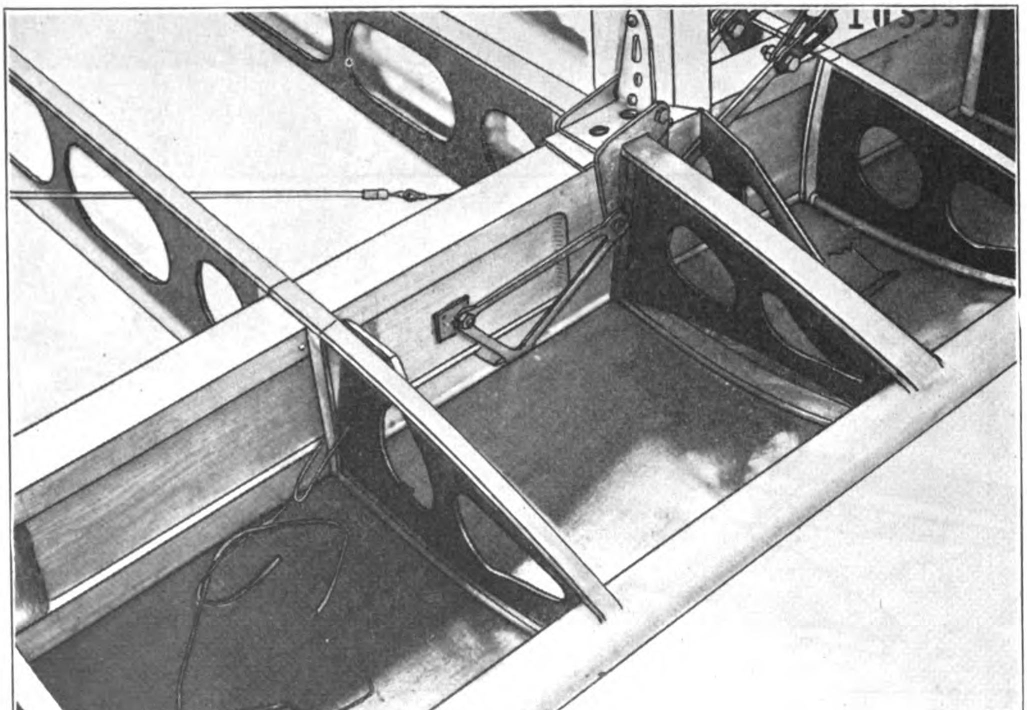


Fig. 12.—Orenco PW-3.

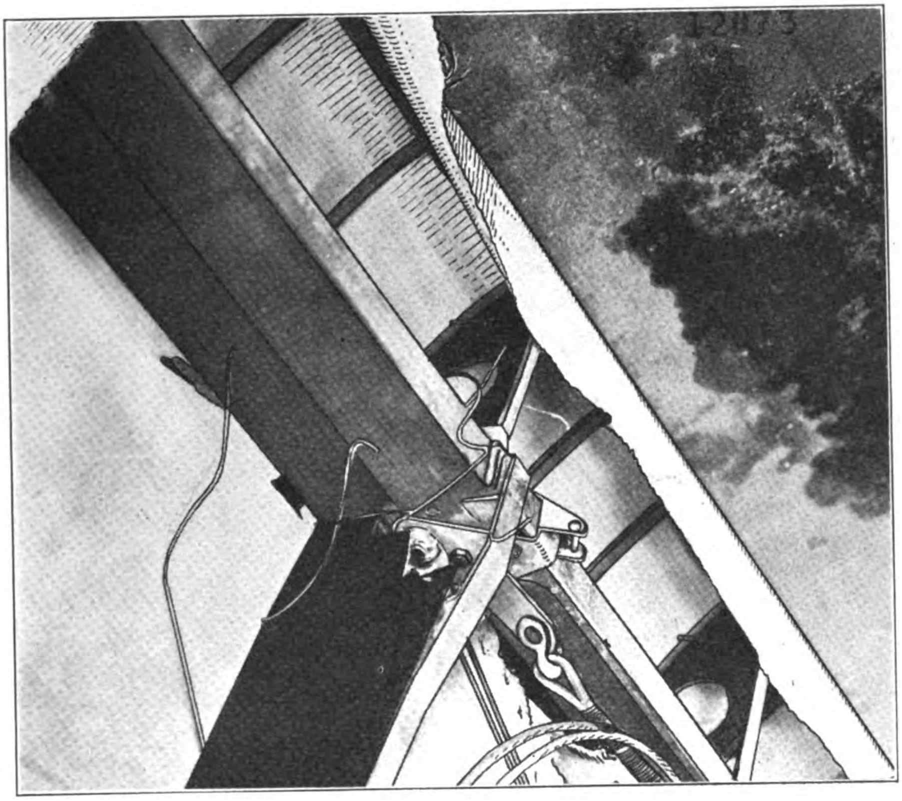


FIG. 13.—Dayton-Wright TA-3.

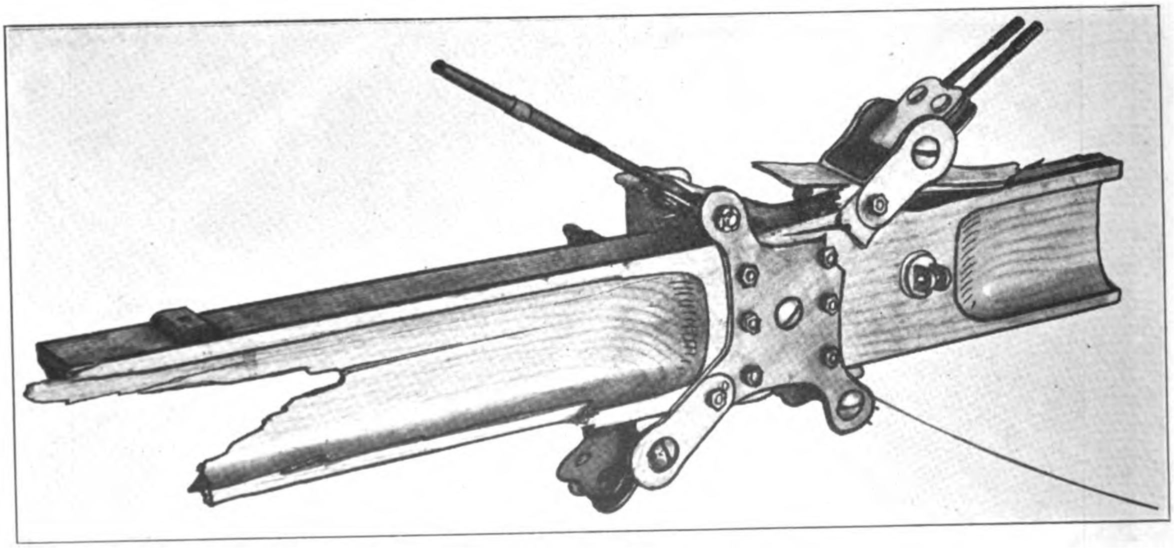


FIG. 14.—GA-1

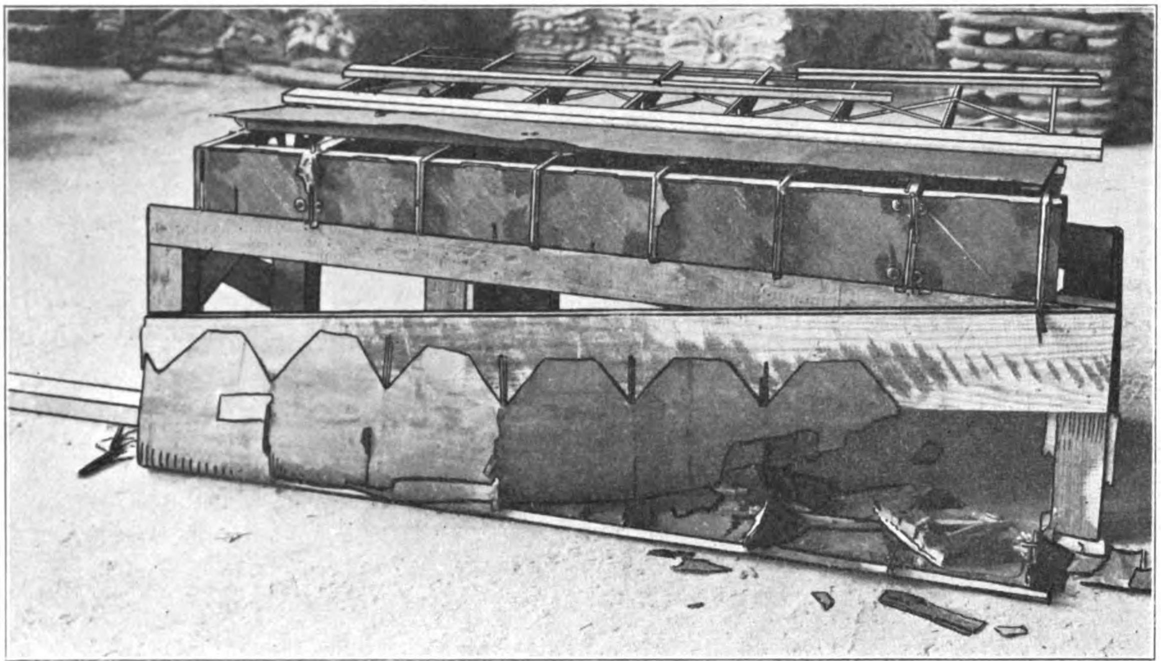


FIG. 15. PW-1.

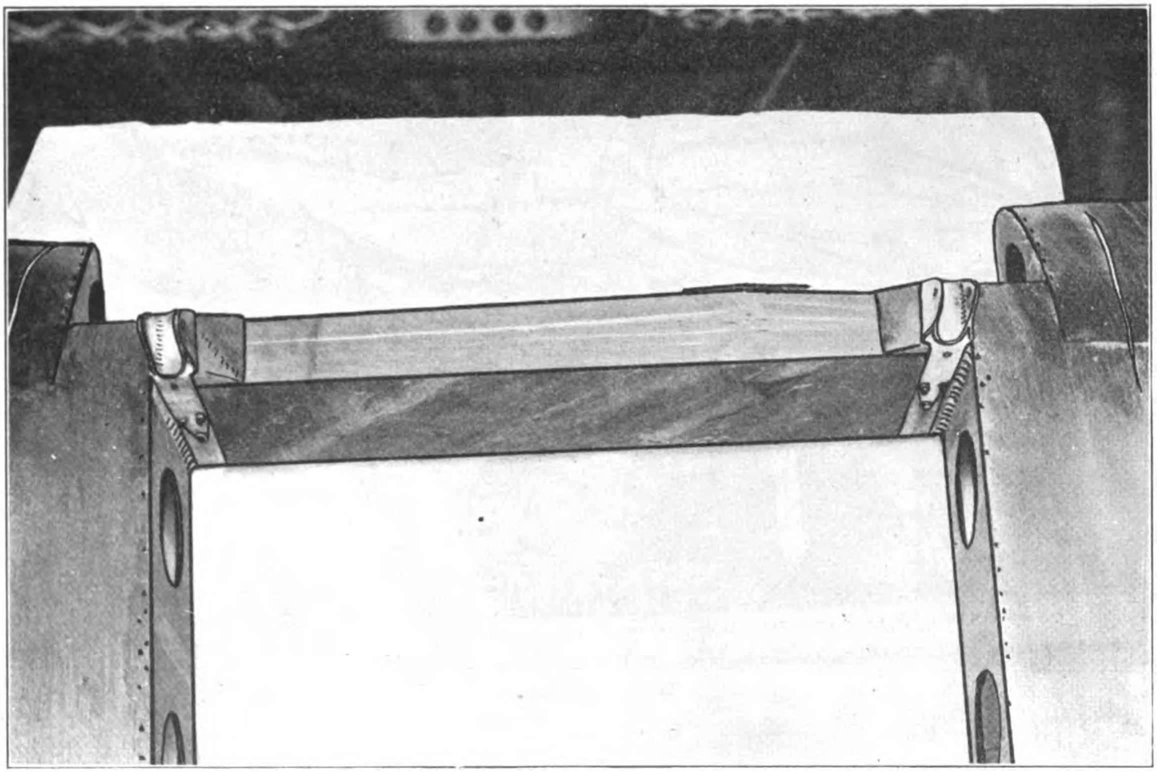


FIG. 16.—PW-1.

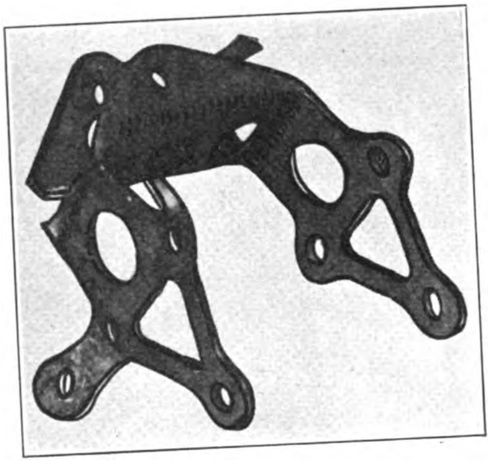


FIG. 17.– PW-1.

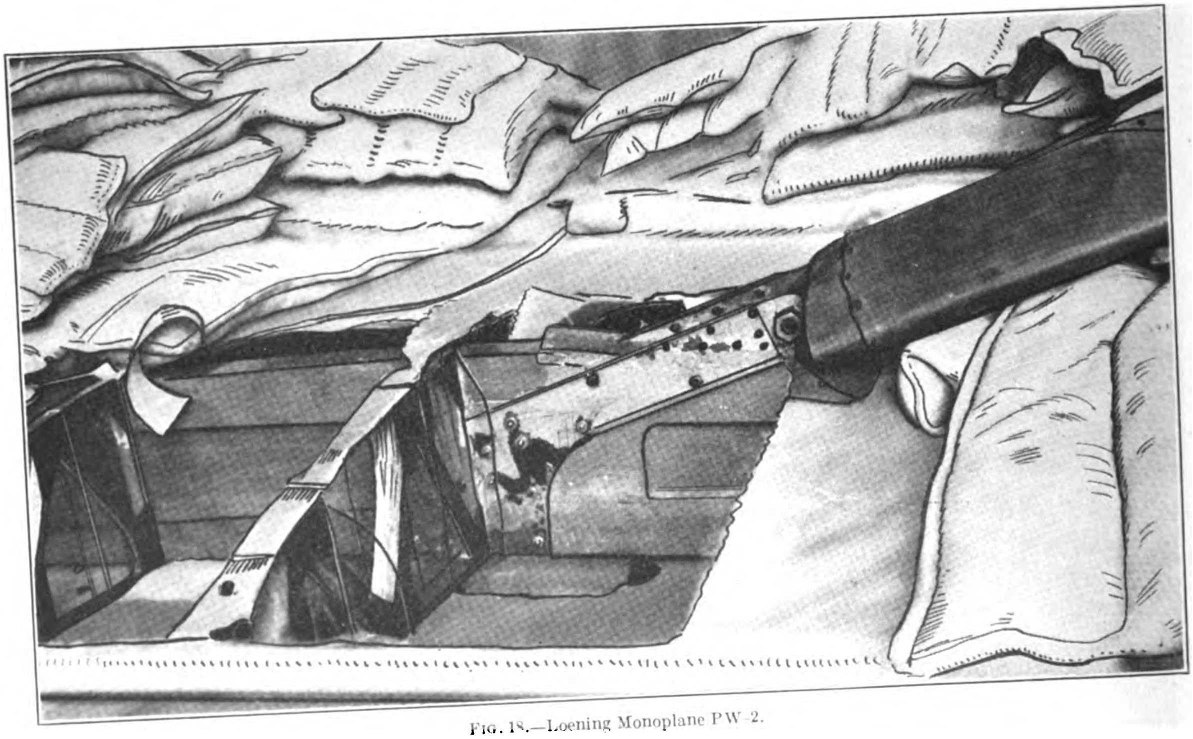


FIG. 18.—Loening Monoplane PW-2.

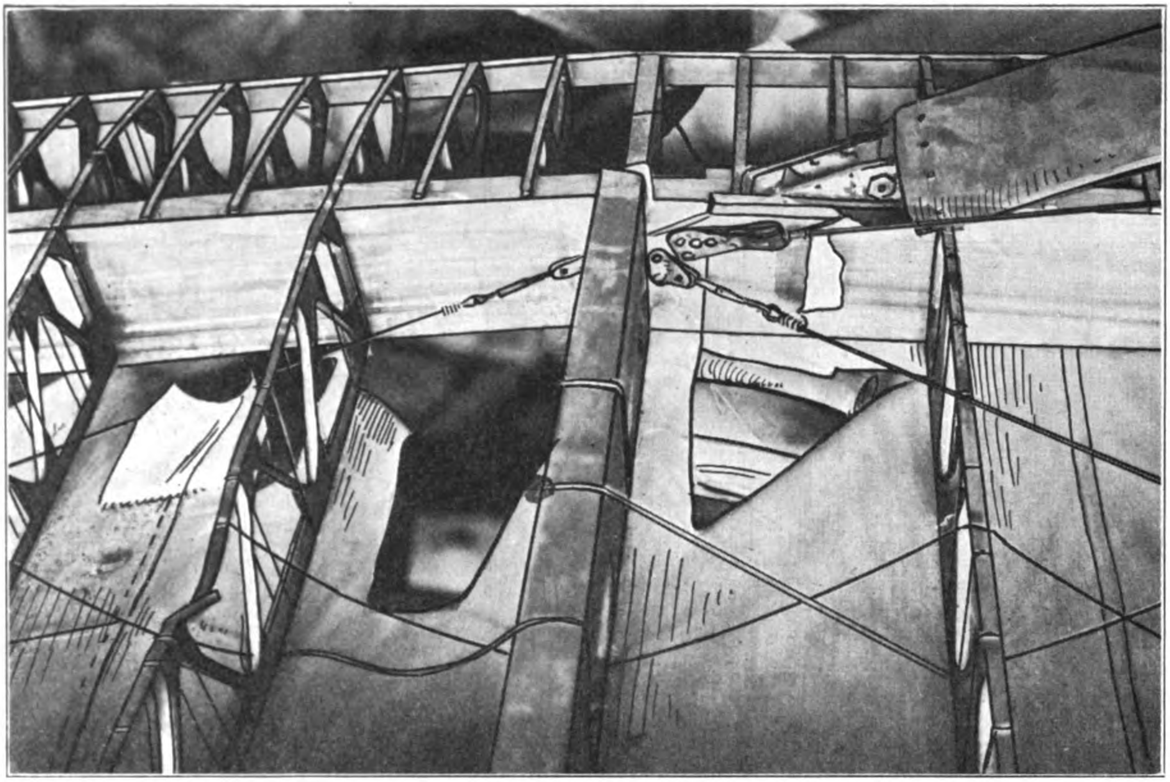


FIG. 19.—Looning Monoplane PW-2

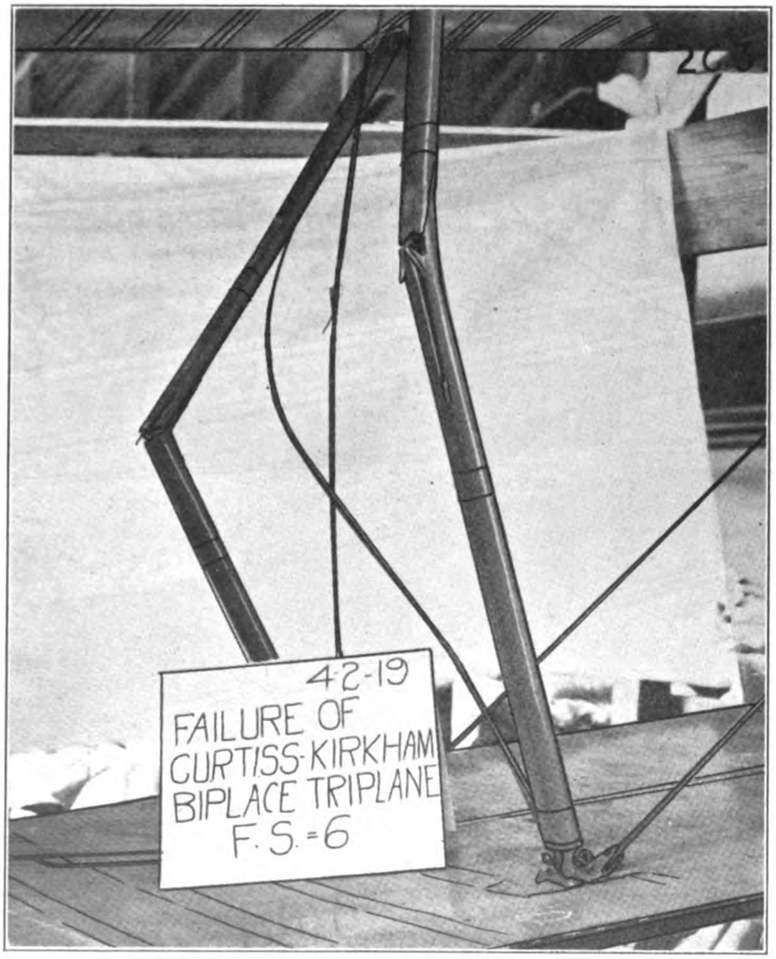


FIG. 20. Curtiss-Kirkham Triplane

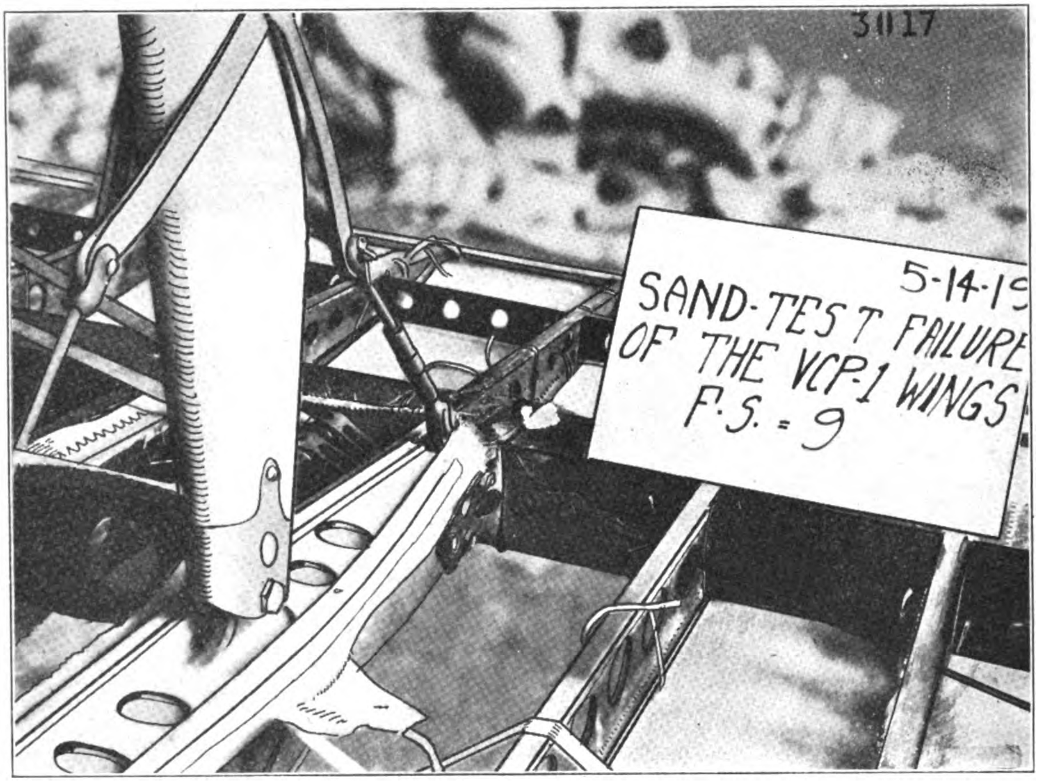


FIG. 21.—VCP-1.

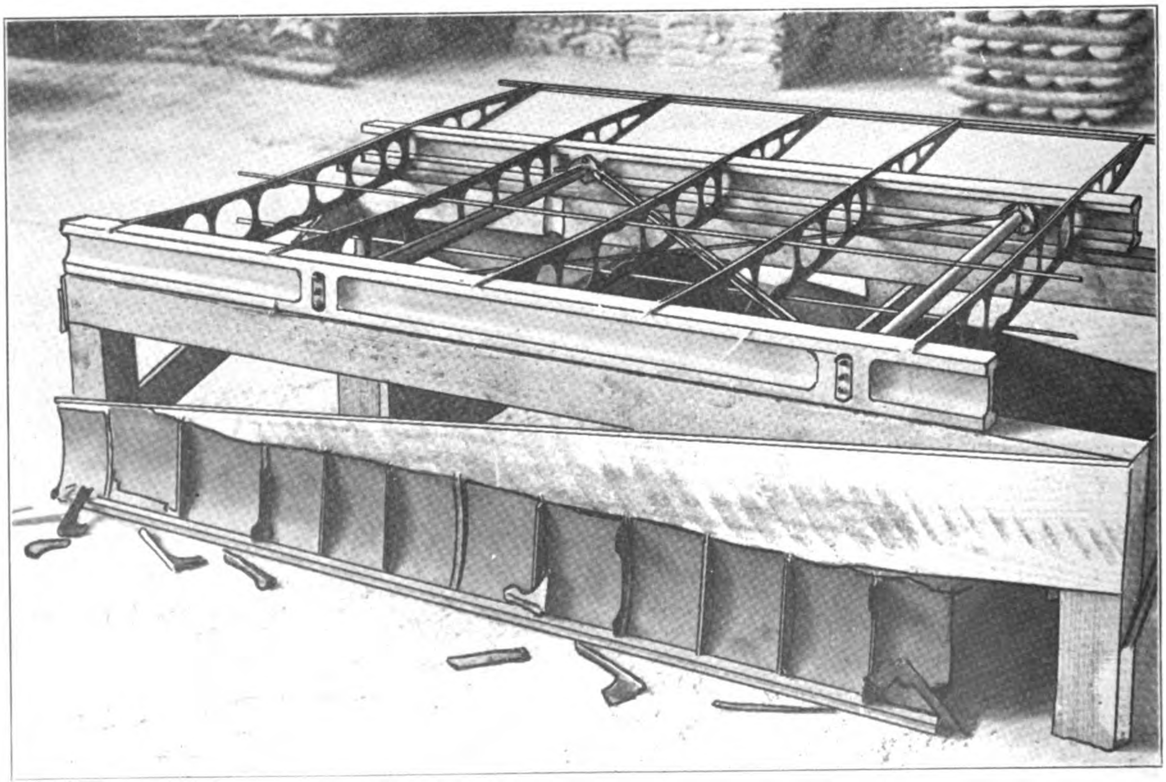


FIG. 22.—TW 1.

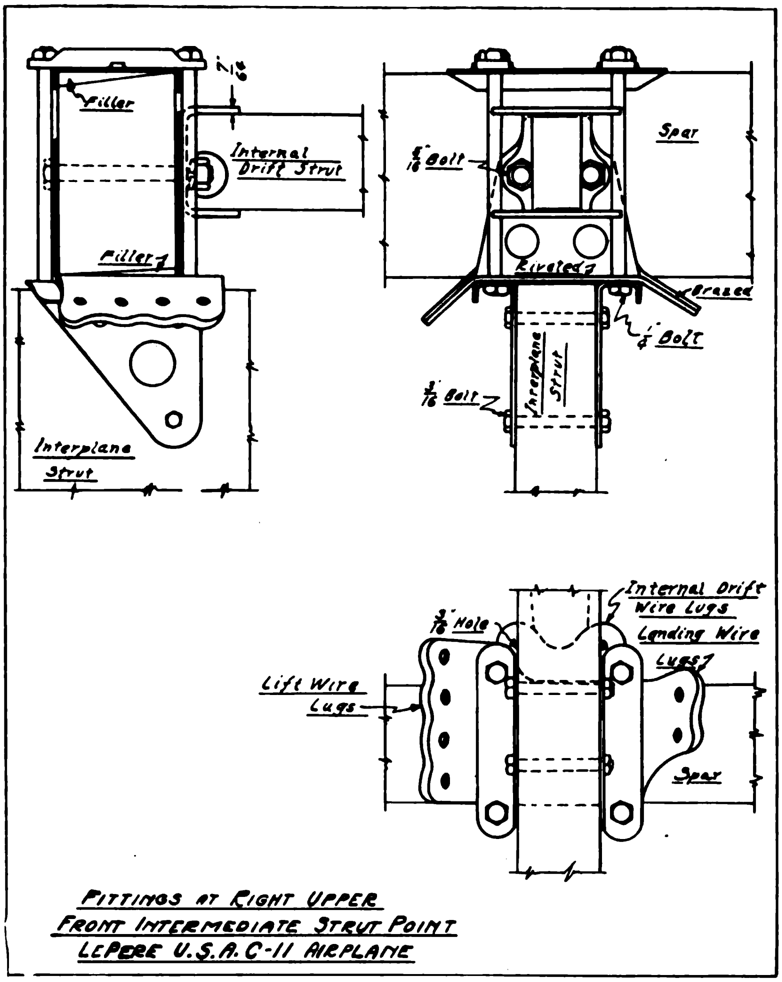

Filler
Internal Drift Strut
Filler
Interplane Strut
Spar
5/16 Bolt
Riveted
Brazed
1/4 Bolt
5/16 Bolt
Interplane Strut
Internal Drift Wire Lugs
5/16 Hole
Landing Wire Lugs
Lift Wire Lugs
Spar
Fittings at Right Upper
Front Intermediate Strut Point
LePere U.S.A.C-11 Airplane

FIG. 23.

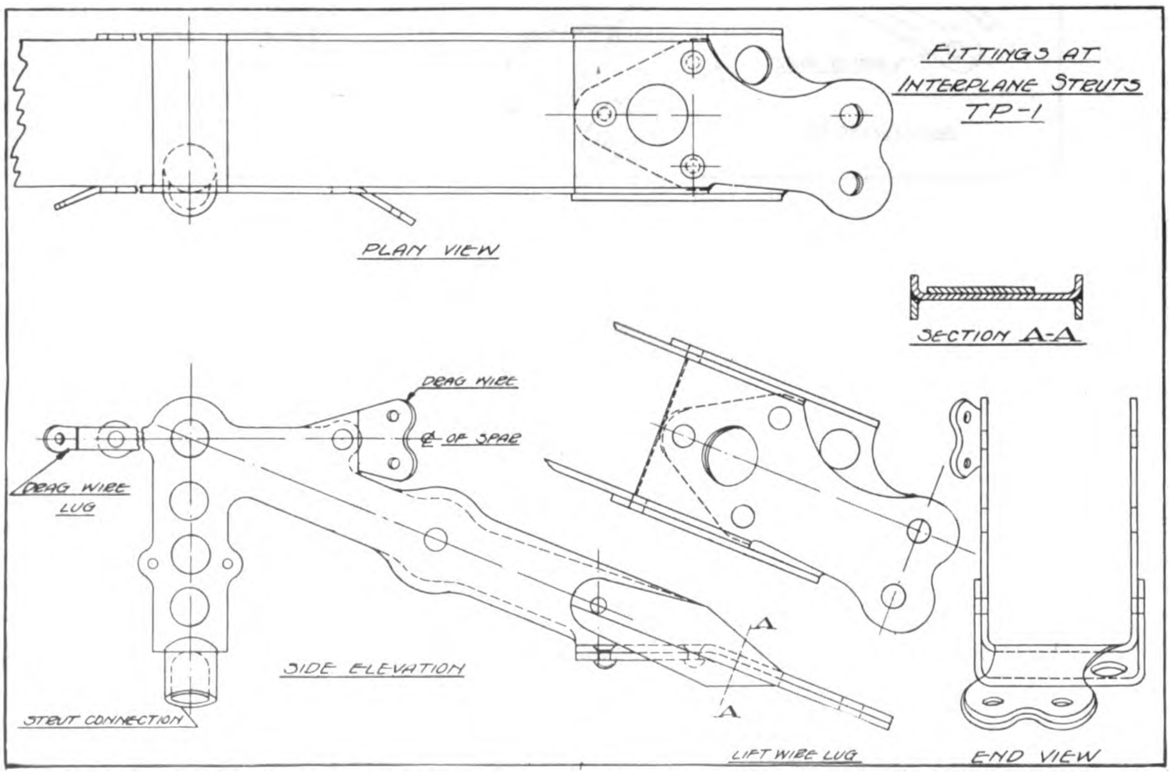

Fittings at Interplane Struts TP-1
Plan View
Section A-A
Drag Wire
℄ of Spar
Drag Wire Lug
A
A
Side Elevation
Strut Connection
Lift Wire Lug
End View

FIG. 24.

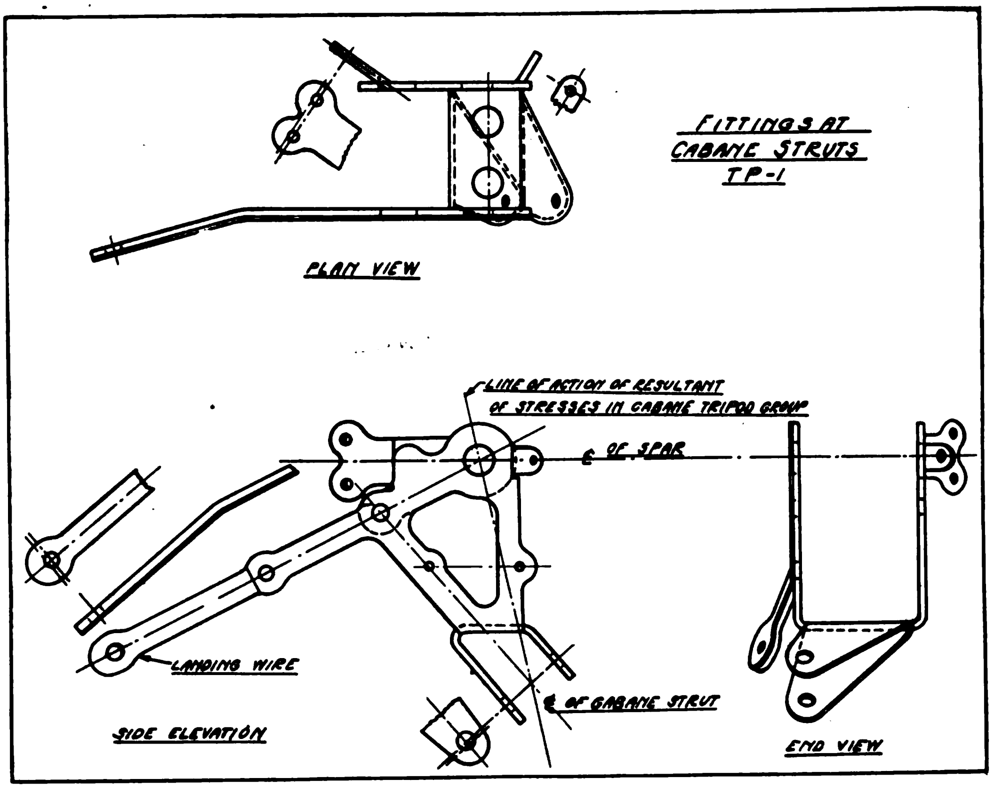

FITTINGS AT
CABANE STRUTS
TP-1
PLAN VIEW
LINE OF ACTION OF RESULTANT
OF STRESSES IN CABANE TRIPOD GROUP
℄ OF SPAR
LANDING WIRE
℄ OF CABANE STRUT
SIDE ELEVATION
END VIEW

FIG. 25.

FOR OFFIC[redacted]

File D 52.1 / Dayton-Wright / 2 McCOOK FIELD REPORT, SERIAL No. 1985

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV December 1, 1922 No. 388

STATIC TEST OF THE DAYTON WRIGHT TA-3 AIRPLANE

(AIRPLANE SECTION, S. & A. BRANCH)

7

Prepared by A. L. Morse
Engineering Division, Air Service
McCook Field, Dayton, Ohio
July 15, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

STATIC TEST OF THE DAYTON WRIGHT TA-3 AIRPLANE.

SUMMARY OF RESULTS.

Airplane: Dayton-Wright TA-3.
Type: XIV.
Total weight: 1,738 pounds.
Wing cellule weight: 335 pounds.
Wing area, 229 square feet.

Engine: LeRhone, 89 horsepower.

Description: The Dayton-Wright TA-3 is a two-place, side by side, training biplane. The wing spars and ribs are wood. The fuselage and tail surfaces are of steel tube construction.

RESULTS OF TEST.

Date.	Part tested.	Load required.	Pounds per square foot or factor supported.	Failed at.	Weight.	Failure.
Jan. 27, 1922	Horizontal stabilizer.	35 pounds per sq. ft.	40 pounds per sq. ft.	None	0.98 pounds per sq. ft.	None.
Do	Elevator	do	do	do	do	Do.
Do	Elevator control	do	do	do		Do.
Jan. 28, 1922	Vertical fin	30 pounds per sq. ft.	60 pounds per sq. ft.	do	1.21 pounds per sq. ft.	Do.
Do	Rudder	do	do	do	0.98 pounds per sq. ft.	Do.
Do	Rudder control	do	do	do		Do.
Jan. 30, 1922	Ailerons	35 pounds per sq. ft.	20 pounds per sq. ft.	do	1.04 pounds per sq. ft.	Do.
Do	Aileron control	do	do	20 pounds per sq. ft.		Link connecting twin control sticks buckled.
	WING CELLULE.					
Feb. 8, 1922	High incidence	8	7.5	8	1.46 pounds per sq. ft.	The lower right rear wing spar attachment fitting pulled out.
Feb. 2, 1922	Low incidence	5.5	5.5	None	do	None.
Jan. 31, 1922	Reverse load	3.5	3.5	do	do	Do.
Mar. 18, 1922	Six-foot length of leading edge.	14	9	9		The leading edge sheared off at the face of the spar.
Mar. 7, 1922	Fuselage	7	9.5	10	142.5 pounds	The lower right longeron buckled.
Mar. 31, 1922	Tail skid	36-inch drop.	18-inch drop.	18-inch drop.	7 pounds	The fuselage supporting the tail skid failed.
Mar. 30, 1922	Chassis:					
	Struts	7.5	6	6		The left rear strut buckled.
	Axle	7	6	None	60 pounds	
	Shock absorber.	6.5	6	do		

OBJECT.

This static test was conducted for the purpose of determining the structural strength of the Dayton-Wright TA-3 airplane submitted in accordance with Contract No. 407. This airplane bears the A. S. No. 64390.

DATE AND PLACE.

The following tests were performed at McCook Field, Dayton, Ohio:

No.	Date.	Tests.
1.	Jan. 27, 1922	Elevator and stabilizer.
2.	Jan. 28, 1922	Rudder and fin.
3.	Jan. 30, 1922	Ailerons.
4.	Jan. 31, 1922	Wing cellule (reverse flight).
5.	Feb. 2, 1922	Wing cellule (low incidence).
6.	Feb. 8, 1922	Wing cellule (high incidence).
7.	Mar. 7, 1922	Fuselage.
8.	Mar. 30, 1922	Landing chassis.
9.	Mar. 18, 1922	Leading edge.
10.	Mar. 31, 1922	Tail skid.

WITNESSES.

Lieut. C. N. Monteith. K. M. Lane.
Lieut. E. W. Dichman. W. E. Savage.
Lieut. C. W. Pyle. E. R. Weaver.

SUMMARY.

WING CELLULE.

The load schedule is based on a total weight of 1,738 pounds and a wing weight of 316 pounds.

Reverse loading.—Load factor required=3.5. Center of gravity of load at 25 per cent of the chord. Angle of inclination of the mean chord=14 degrees, trailing edge down. The load was carried to a factor of 3.5 without failure.

Low-incidence loading.—Load factor required=5.5. Center of gravity of load at 48 per cent of the chord. Angle of inclination of mean chord=4° 36′, trailing edge down. The load was carried to a factor of 5.5 without failure.

High-incidence loading.—Load factor required=8.0. Center of gravity of load at 28 per cent of the chord. Angle of inclination of mean chord=10°, leading edge down. The upper right front spar at the outer strut point failed at a load factor of 6. The right upper and lower outer panels were interchanged and reinforced at the outer strut. The center section front spar fittings and fitting attaching lower rear spars to fuselage failed at a load factor of 8.

Test of leading edge of wing.—Load factor required=14. Leading edge failed at a load factor of 9.

Ailerons.—Load required=35 pounds per square foot. The compression member connecting the control sticks failed at 20 pounds per square foot.

ELEVATOR AND STABILIZER.

Load required=35 pounds per square foot.
Elevators failed at 40 pounds per square foot.

RUDDER AND FIN.

Load required=30 pounds per square foot.
Rudder failed at 60 pounds per square foot.

FUSELAGE (IN BENDING).

Load factor required = 7.

Load on the engine mount was carried to a load factor of 8 without failure. The rear portion of the fuselage failed at a load factor of 10.

IMPACT TEST OF TAIL SKID AND FUSELAGE.

Required load: Drop of 36 inches with normal load in tail-low position. Fuselage failed at 18 inches and normal load.

CHASSIS.

Load factor required=7.5.
Struts failed at a load factor of 6.

GENERAL RECOMMENDATIONS.

WINGS.

Redesign the front spar, center section front spar fittings, fittings attaching lower rear spars to the fuselage, compression members in the drag truss of the upper wing at the outer interplane strut, and leading edge structure of the wing.

Ailerons—Redesign the compression member connecting the control sticks.

ELEVATORS AND STABILIZER.

None.

RUDDER AND FIN.

None.

FUSELAGE (IN BENDING).

None.

FUSELAGE (IMPACT TEST OF TAIL SKID AND FUSELAGE).

Redesign the fuselage where tail skid is mounted.

CHASSIS.

Redesign.

GENERAL DESCRIPTION.

The Dayton-Wright TA-3 airplane is a two-place side by side training biplane. The wing spars and ribs are of wood construction with metal interplane struts. The fuselage and tail surfaces are of steel tube construction welded at the joints. All surfaces are fabric covered. The landing gear is constructed of steel tubing. The motor is a Le Rhone which delivers 89 horsepower at 1,250 revolutions per minute.

The desired performance is as follows:

(*a*) 90 miles per hour at sea level.
(*b*) Climb to 10,000 feet in 15 minutes.
(*c*) Service ceiling—14,000 feet.
(*d*) Landing speed not in excess of 45 miles per hour.

Total weight	1,738 pounds.
Wing area	229 square feet.
Weight per sq. ft	7.6 pounds.
Weight per horsepower	19.5 pounds.
Aerofoil used	U. S. A-27.
Useful load	603 pounds.

The list of equipment is in accordance with the specifications for this type of airplane.

Figure 1 is a plan view of the TA-3 airplane.

Figure 2 is a front and side elevation of the TA-3 airplane.

WING CELLULE.

DESCRIPTION.

The wing cellule is a single bay biplane with interchangeable upper and lower wings, and an unusually large center section. The center section is supported forward by two tripods of steel streamline struts and aft by two struts on the right and one on the left. There are adjustable interplane N-struts which slope upward and outward and there is but one lift wire to each spar. These wires are crossed. The one landing wire is in the forward truss.

Below are given the general wing characteristics:

Section	U. S. A.-27.
Chord	54 inches.
Mean gap	58½ inches.
Stagger	18 inches.
Incidence upper	2°.
Incidence lower	2°.
Dihedral upper	2.75°.
Dihedral lower	2.75°.
Span upper	30 feet 11$\frac{11}{16}$ inches.
Span lower	25 feet 10$\frac{7}{16}$ inches.
Weight of wings	335 pounds.
Weight per sq. ft	1.46 pounds.

The wings are of the usual wood construction with spruce "I" section spars and spruce leading and trailing edges. The main ribs are of the built-up semitruss type with basswood web and truss members and split spruce cap strips. There are three compression ribs in the two-bay drag truss. These are of the box type, having two upper and two lower spruce flanges and Spanish cedar plywood sides. The ribs are laterally braced by fabric tape which is crossed between each rib. Details of the wing may be seen in figure 3. The center section is of the same type of construction. Its contour is broken by a large "triplex" glass window in the center with the two main gas tanks on either side. Details of the center section may be seen in figure 4.

PROCEDURE FOR TEST (REVERSED FLIGHT).

The wings were assembled on the airplane as for flight and loaded according to the loading schedule in figure 5. The angle of inclination of the wing chord to the horizontal was 14° leading edge down, and the center of gravity of the load was located at 25 per cent of the wing chord, as specified in the "Handbook for Designers."

RESULTS.

The wings supported a load factor of 3.5 without signs of failure. The longest of the forward center section sup-

porting struts showed lateral deflections of $\frac{1}{8}$ inch and $\frac{3}{16}$ inch, respectively. Figure 6 is a table of deflections and Figure 7 shows the deflection curves.

DISCUSSION.

The wings were required to support a load factor of 3.5.

CONCLUSION.

The wings supported the required load in a satisfactory manner.

PROCEDURE FOR TEST (LOW INCIDENCE).

The wings were assembled as for flight and the airplane inverted with the angle of inclination of the wing chord to the horizontal (angle γ) equals 4° 36′ with the trailing edge down. The wings were then loaded according to the loading schedule in Figure 8 with the center of gravity of the load located at 48 per cent of the chord from the leading edge corresponding to the position of the center of pressure at low incidence. Angle γ was determined as follows:

Angle of incidence $\alpha=0° \, 12'$.

$$\beta=\cot^{-1}L/D=\cot^{-1} 11.9.$$
$$\beta=4° \, 48'.$$
$$\gamma=\beta-\alpha=4° \, 36'.$$

RESULTS.

The wings supported a load factor of 5.5 without signs of failure. Figure 9 is a table of deflections and Figure 10 shows the deflection curves.

DISCUSSION.

The wings were required to support a load factor of 5.5.

CONCLUSION.

The wings supported the required load in a satisfactory manner.

PROCEDURE FOR TEST (HIGH INCIDENCE).

The wings were assembled as for flight and the airplane inverted, the angle of inclination of the wing chord to the horizontal (angle γ) equals 10° leading edge down. The wings were then loaded according to the loading schedule in Figure 11, with the center of gravity of the load located at 28 per cent of the chord from the leading edge, corresponding to the position of the center of pressure at high incidence. Angle γ was determined as follows:

Angle of incidence $\alpha=17°$.

$$\beta=\cot^{-1}L/D=\cot^{-1} 8.2$$
$$\beta=7°.$$
$$\gamma=\beta-\alpha=-10°.$$

RESULTS.

The wings failed at a load factor of 6 in the following manner: The forward spar of the right upper wing split longitudinally through the routing. The split was about five feet long and appeared to have originated at the point of the interplane strut attachment. The lower half of the spar, at this point, was rotated axially and clockwise, as seen from the pilot's seat, crushing the light plywood sides of the compression rib. Figure 30 is a photograph of the failure. Figure 12 is a table of spar deflections and Figure 13 shows the deflection curves.

DISCUSSION.

The wings were required to support a load factor of 8. The failure seems to have been caused by the combined effects of longitudinal shear and a couple due to the eccentric forces of the interplane strut and the drag and lift wires. Figure 14 shows the conditions at the point of failure.

Because of this local failure no conclusions could be drawn as to the strength of the wings as a whole, so it was necessary to strengthen the parts in the locality of the failure and conduct a new test.

PROCEDURE FOR TEST.

The procedure was the same as in the first test. The loading schedule may be seen in Figure 15. The repairs and additions to the wings were as follows: The front spars were stiffened by $\frac{1}{4}$-inch by $1\frac{1}{8}$-inch oak blocks. Four of these were screwed to the sides of the spar on either side of the interplane strut attachment fitting front and rear. The routing was filled with spruce blocks where necessary. The compression ribs were reinforced by a $\frac{9}{16}$-inch by $3\frac{1}{2}$-inch white pine member placed against the outboard side of the compression rib. The right upper and lower wings were interchanged. Figure 31 shows the repairs.

RESULTS.

The wings failed at a load factor of 8. The lower right rear wing spar attachment fitting at the fuselage pulled out while the jacks were being let down. Figure 32 is a photograph of the failure. Figure 16 is a table of spar deflections and Figure 17 shows the deflection curves. After the test the forward center section support fittings were found to have been torn. Figure 33 and 34 show this failure.

DISCUSSION.

The wings were required to support a load factor of 8. The above fitting pulled out before the wings fully supported this load.

CONCLUSIONS.

The wings did not support the required load in a satisfactory manner.

RECOMMENDATIONS.

It is recommended that the lower rear spar attachment and that the upper wings in the region of the interplane strut attachment be redesigned.

ELEVATOR AND STABILIZER.

DESCRIPTION.

The elevator and stabilizer are constructed of seamless steel tubing, welded at the joints. The stabilizer is braced with wires at the front and rear spars. False ribs of spruce extend from the leading edge to the forward spar of the stabilizer. The elevators are interchangeable with the rudder. The control horns are made of 0.065-inch flat steel plate with spruce stiffeners. Details of the elevator and stabilizer may be seen in Figure 18. The elevators are not balanced.

TABLE OF WEIGHTS AND AREAS.

	Weight.	Area.	Weight per square foot.
	Pounds.	*Square feet.*	*Pounds.*
Elevators	10	10.2	0.98
Stabilizer	13½	14.7	
Wires	1¼		.98

The controls are of the usual stick type with cables running from the horns of each elevator through the fuselage to horns on the torque tube to which the two control sticks are attached. The stabilizer is mounted solidly on the fuselage and has no adjustment.

PROCEDURE FOR TEST.

The stabilizer and elevator were mounted on the fuselage as for flight, and a spring balance was attached to the control stick to register the pull on the stick. The surfaces were then loaded according to the loading schedule in Figure 19. The load distribution over the elevators was such as to place the center of gravity of the load at $\frac{5}{12}$ the chord from the hinge center line.

RESULTS.

Figure 19 shows the deflections and results of the test. The horizontal tail surface stood the test without failure. They were loaded up to 40 pounds per square foot, after which a permanent warp in the trailing edge was noted. Figure 35 is a photograph of the warped trailing edge.

DISCUSSION.

The required loading per square foot for the stabilizer and elevator is 35 pounds. As the surfaces stood a load of 40 pounds per square foot without failure of either the surfaces or control system, it is evident that they are strong enough structurally.

CONCLUSION.

The elevator, stabilizer, and control system have sufficient strength.

RUDDER AND FIN.

DESCRIPTION.

The rudder and fin are of the same type of construction as the elevator and stabilizer. They are made of steel tube, welded at the joints. The fin is braced with wires at the front and rear spars, and has false nose ribs of spruce. The rudder is interchangeable with the elevators and is not balanced. Details of the rudder and fin may be seen in Figure 20.

TABLE OF WEIGHTS AND AREAS.

	Weight.	Area.	Weight per square foot.
	Pounds.	*Square feet.*	*Pounds.*
Rudder	5	5.1	0.98
Fin	4	4.35	
Wires	1¼		1.21

The controls consist of two steel tube rudder bars placed side by side with a horn projecting forward from the middle of each rudder bar. The extremities of these horns are connected by a steel tubular link in order that the rudder bars may turn simultaneously. The two cables to the rudder are attached to the outboard side of each rudder bar. The connecting link is always in tension.

PROCEDURE FOR TEST.

The rudder and fin were mounted on the fuselage as for flight. The surfaces were then loaded according to the loading schedule in Figure 21. A spring balance was attached to the middle of the foot rest of the rudder bar to which the control cable under load was attached, in order to register the force on the foot bar. The center of gravity of the load on the rudder was located at $\frac{5}{12}$ of the mean chord from the hinge center line.

RESULTS.

Figure 21 shows the deflections and results of the test. The rudder and fin were loaded up to 60 pounds per square foot without a failure, after which a permanent warp in the trailing edge was noted. Figure 36 is a photograph of the warped trailing edge.

DISCUSSION.

The rudder and fin were required to support 30 pounds per square foot. They supported 60 pounds per square foot without failure in the surfaces or control system.

CONCLUSION.

The rudder and fin are too heavy.

RECOMMENDATIONS.

It is recommended that the rudder and fin be redesigned.

AILERONS.

DESCRIPTION.

The ailerons are interchangeable and of wood construction. The box spar consists of an upper and lower spruce flange connected by webs of three-ply mahogany. Filler blocks are placed in the spar at the points where the horn and hinge fittings are attached. The trailing edge is of spruce and the outboard contour member is an ash bow. All of the ribs have basswood webs and spruce cap strips. Details of the aileron may be seen in figure 22.

TABLE OF WEIGHTS AND AREAS.

	Weight.	Area.	Wt. per sq. ft.
	Pounds.	*Sq. ft.*	*Pounds.*
Aileron	7	6.75	1.04

There are ailerons on both upper and lower wings. The aileron on the the upper wing is actuated by a strut which connects it to the aileron on the lower wing. The aileron on the lower wing is actuated by a rod which runs from the single aileron horn to a triangular bell-crank lever. To the triangular bell-crank lever are attached the two control cables. One of these cables is continuous through the fuselage. The other cable passes over a pulley in a line about which the twin control sticks pivot when moved fore and aft, and crosses over to the lower extremity of the

opposite control stick, which is below the pivot line. The twin sticks are connected by a steel tubular link at their lower extremities, which causes the sticks to swing simultaneously. The interaileron strut and the aileron horn are not attached to the same rib.

PROCEDURE FOR TEST.

The wings and ailerons were mounted on the fuselage as for flight. A spring balance was attached to the right control stick, in order to register the pull on the stick, and the right upper and lower ailerons were loaded according to the loading schedule in figure 23. No deflection readings were taken. The center of gravity of the load on the aileron was located at 5/12 of the chord from the hinge center line.

RESULTS.

Figure 23 shows the results of the test. At a load of 10 pounds per square foot there was an excessive deflection in both ailerons. At a load of 20 pounds per square foot the link connecting the twin control sticks buckled. Figure 37 is a photograph of the failure of the connecting link. The triangular bell-crank lever support pulled away from the spar. Figure 38 is a photograph of this failure.

DISCUSSION.

The required loading per square foot on the aileron was 35 pounds. The ailerons showed excessive deflections under a load of 10 pounds per square foot and the control mechanism failed at a load of 20 pounds per square foot.

CONCLUSION.

Since the abnormal deflection was due largely to the design of the control system, and since the control system failed so soon, no conclusions can be made as to the structural strength of the ailerons. It is evident, however, that the control system is weak.

RECOMMENDATIONS.

It is recommended that the control mechanism be redesigned.

FUSELAGE.

DESCRIPTION.

The fuselage is of steel tube and wire construction. It is rectangular in section and has four steel tube longerons. The joints are welded with gusset plates in the corners, which serve as anchorages for the swaged bracing wires. The mounting for the rotary motor consists of a reinforced sheet-steel bulkhead, which supports the motor directly behind the cylinders, and a pyramid of four steel tubes, which support the rear end of the crank shaft, and which connect the longeron bulkhead joints to the ring which supports the crank shaft. There is a door on the right-hand side of the fuselage, which is locked in such a way that the stresses in the upper longeron are continuous through the door. The weight of the fuselage is 142.5 pounds. Details of the fuselage may be seen in figure 24. Figure 39 is a photograph of the engine mounting.

PROCEDURE FOR TEST.

The fuselage was hung in a jig in such a way that it was supported at the wing hinges. The fuselage was loaded, as shown in the loading schedule in Figure 25. The spacing of the deflection points is shown in Figure 26. The engine load was hung on a jig. Figure 39 is a photograph of this jig.

RESULTS.

The fuselage failed at a load factor of 10. The lower right longeron two bays back of the cockpit failed by buckling. Figure 26 shows the results of the fuselage test. Figure 40 is a photograph of the longeron failure.

DISCUSSION.

The fuselage was required to support a load factor of 7.

CONCLUSION.

The fuselage supported the required load in a satisfactory manner.

LEADING EDGE TEST.

DESCRIPTION.

The wings of the Dayton-Wright TA-3 have a spruce leading edge. The contour from the front spar to the leading edge is maintained by two laminated formed strips between each main rib. These are in the upper surface only. Fabric covering is used.

PROCEDURE FOR TEST.

A 6-foot section from the upper wing panel was placed in an inverted position and supported along the spars. A counterbalance was placed on the rear spar and the leading edge loaded in 10-pound increments until failure. Figure 27 is a diagrammatic drawing of the set-up and loading.

RESULTS.

At a load factor of 9 the leading edge sheared off at the face of the front spar. Figure 27 gives the result of the leading edge test.

DISCUSSION.

The leading edge was required to support a load factor of 14. It failed at 9.

CONCLUSION.

The leading edge did not support the required load in a satisfactory manner.

RECOMMENDATIONS.

It is recommended that the leading edge be strengthened.

LANDING GEAR TEST.

DESCRIPTION.

The landing gear is constructed of steel tubing. It has two wheels and the usual "V" struts on each side. There are two axles, however, which cross each other and pivot on the opposite side of the fuselage from the wheel. The shock absorber cord is wound on fore and aft spindles, which are located at the apex of the "V" struts. The weight of the landing gear structure is 60 pounds. The weight of the wheels is 55 pounds. Figure 28 is a drawing of the landing gear.

PROCEDURE.

The landing gear was set in the testing jig in such a manner that the line of reaction coincided with a line passing from the wheels through the center of gravity of the air-

plane. The center of gravity of the testing load was directly over the axle. The wheels were removed and the axles set in cradles. The load was applied, as shown in the loading schedule in Figure 29.

RESULTS.

The landing gear failed at a load factor of 6. The left rear strut buckled. As the shock absorbers deflected the axles moved laterally in the cradles 1¼ inches. The results are tabulated in Fgure 29. Figure 41 is a photograph of the failure.

DISCUSSION.

The landing gear was required to support a load factor of 7.5. The lateral movement of the axles would undoubtedly severely stress the wheels.

CONCLUSION.

The landing gear did not support the required load in a satisfactory manner.

RECOMMENDATIONS.

It is recommended that the landing gear be redesigned.

TAIL SKID TEST.

DESCRIPTION.

The tail skid is formed out of steamed hickory. It is pivoted in the middle and swivels on the last bottom cross member of the fuselage, which is reinforced by a tripod of steel tubes. The weight of the tail skid is 7 pounds.

PROCEDURE FOR TEST.

The fuselage with the tail skid attached was hung in a jig in the following manner: The front end of the fuselage was pivoted about a transverse axis which made an angle of 14° with the horizontal. A load of 287.5 pounds including, the weight of the fuselage, was placed on the rear end of the fuselage over the tail skid and securely fastened. The tail skid was then lifted off the floor and allowed to drop. The height to which it was raised was stepped up in 6-inch increments until the failure occurred.

RESULTS.

When the tail skid was dropped from a height of 18 inches the following failures occurred: The cross tubes of the fuselage to which the swivel was attached was rotated forward and upward, deforming the two vertical members of the reinforcing tripod and breaking the horizontal member. The skid itself was slightly cracked. Figure 42 is a photograph of the failure.

DISCUSSION.

It was required that the tail skid and its support should withstand a drop of 36 inches.

CONCLUSION.

The tail-skid support did not meet the requirements in a satisfactory manner.

RECOMMENDATIONS.

It is recommended that the fuselage in the vicinity of the tail skid be redesigned.

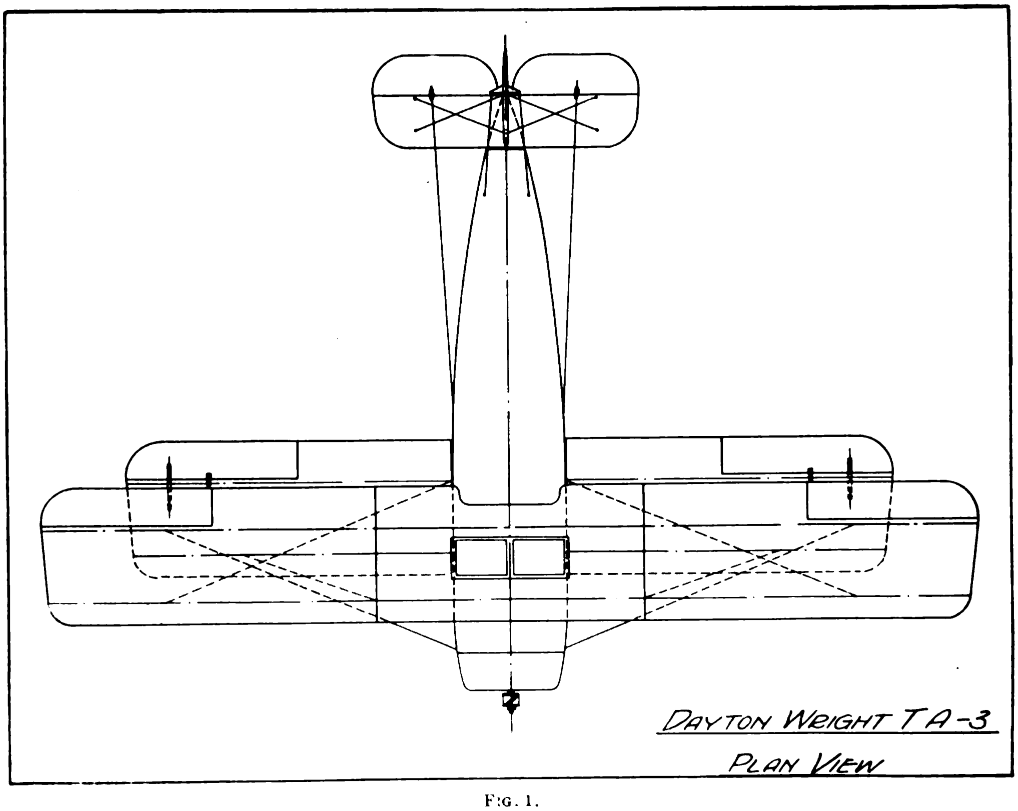


FIG. 1.

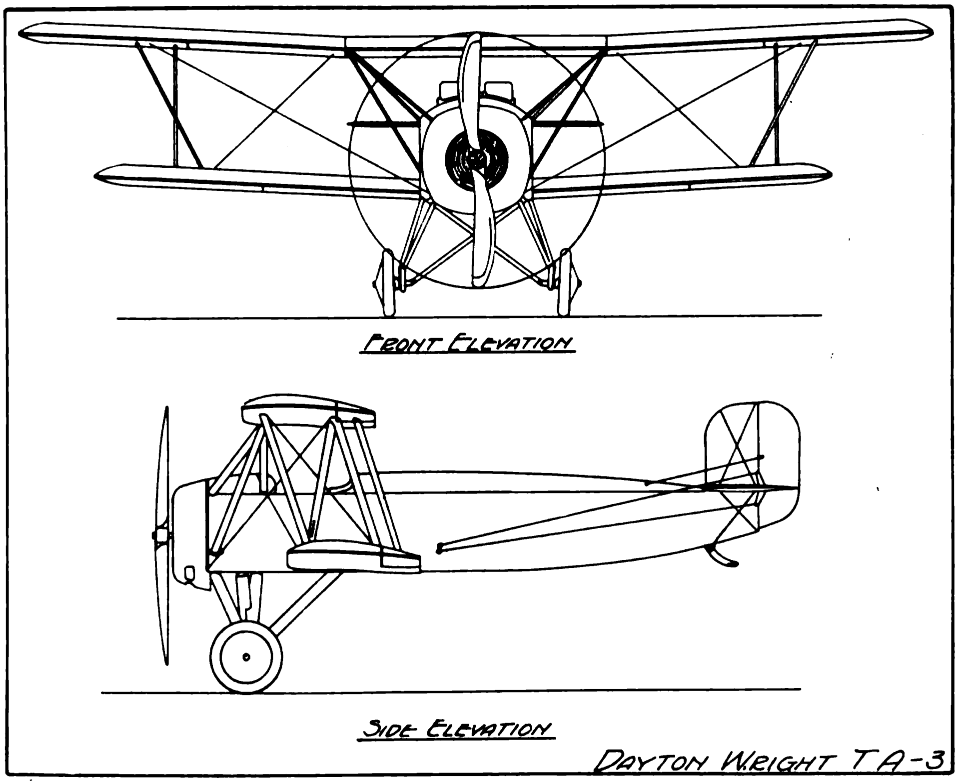


FIG. 2.

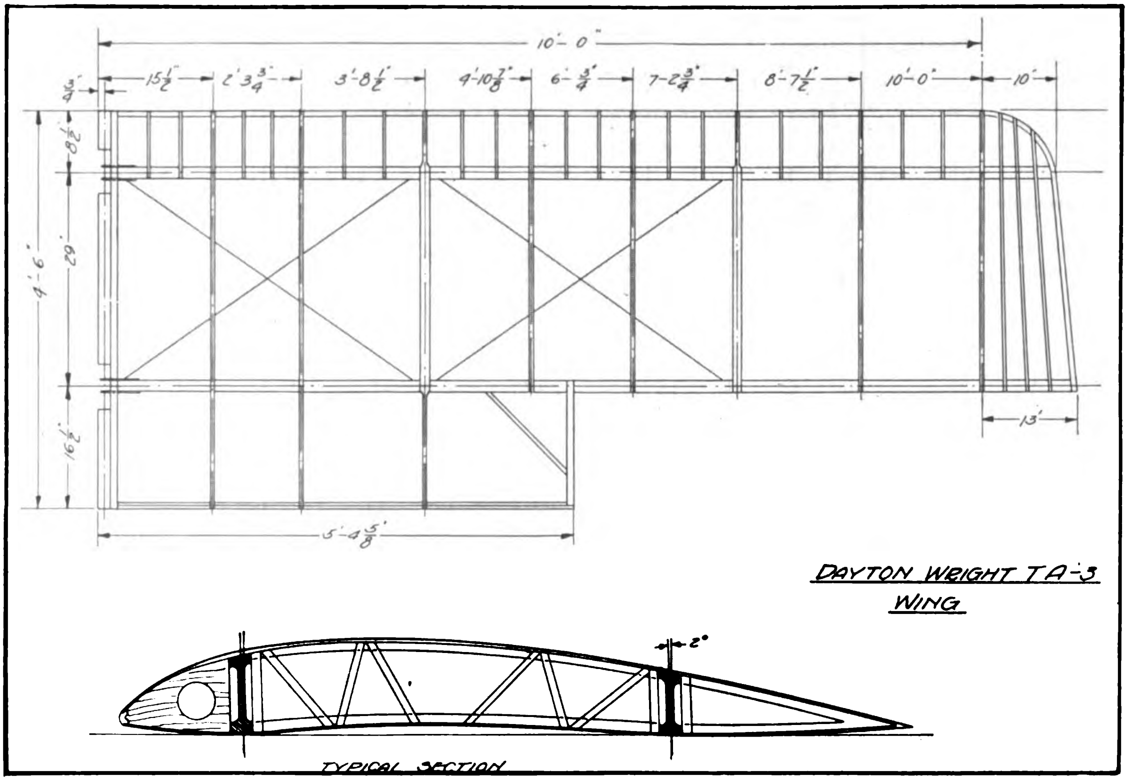


FIG. 3.

14976—22——2

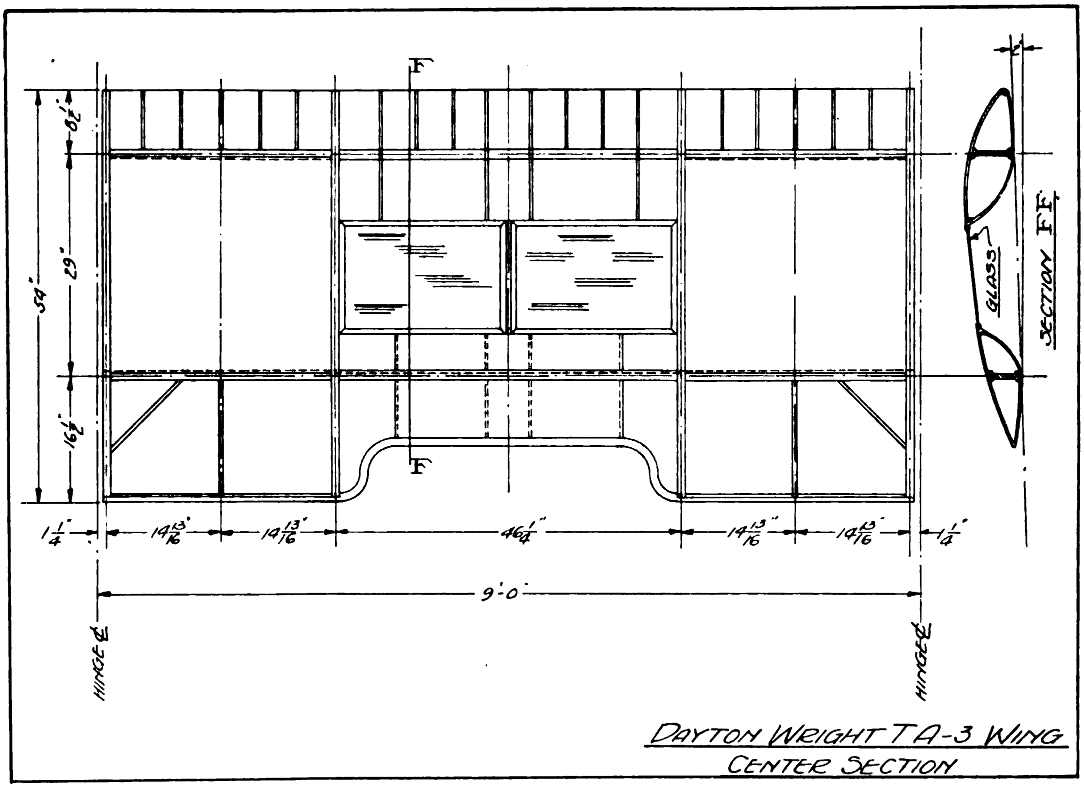
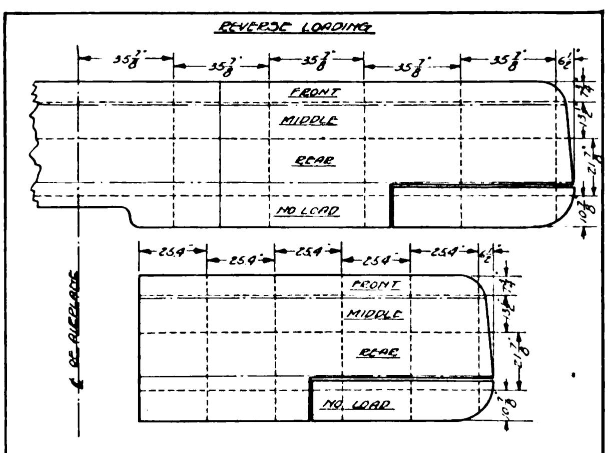


FIG. 4.



REVERSE LOADING								
LOADING SCHEDULE FOR UPPER AND LOWER WINGS								
LOAD	UPPER WING			TOTAL	LOWER WING			TOTAL
FACTOR	FRONT	MIDDLE	REAR	LOAD	FRONT	MIDDLE	REAR	LOAD
2	730	370	360	1460	530	270	270	1070
2.5	940	470	460	1870	680	350	340	1370
3	1150	570	560	2280	830	430	410	1670
3.5	1360	670	660	2690	980	510	480	1970

SINCE THE SPAN OF BOTH UPPER AND LOWER WINGS ARE DIVIDED INTO TEN PARTS, THE LOAD PER SECTION MAY BE FOUND BY DIVIDING THE ABOVE VALUES BY TEN.

DAYTON WRIGHT TA-3

FIG. 5.

REVERSE LOADING

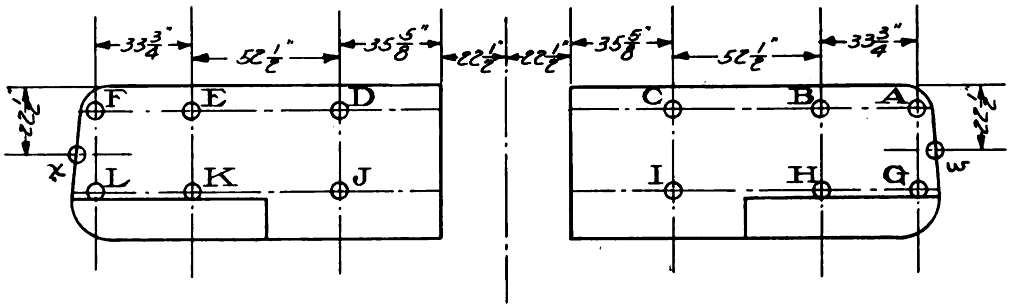


TABLE OF LOWER WING SPAR DEFLECTION IN INCHES																
LOAD FACTOR	FRONT SPAR						REAR SPAR						RETREAT			
	RIGHT			LEFT			RIGHT			LEFT			LOWER		UPPER	
	A	B	C	D	E	F	G	H	I	J	K	L	w	x	w	x
2	1.0	0.7	0.3	0.2	0.4	0.5	1.1	1.0	0.3	0.3	0.8	0.7	-.3	-.3	-.2	+.1
2.5	1.3	0.9	0.5	0.3	0.6	1.0	1.4	1.2	0.4	0.4	1.1	1.3	-.5	-.5	-.4	+.2
3	1.7	1.2	0.6	0.4	0.9	1.3	2.1	1.5	0.5	0.6	1.5	1.8	-.7	-.5	-.4	+.5.
3.5	2.0	1.4	0.7	0.5	1.2	1.8	2.2	1.9	0.7	0.7	2.0	2.5	-.9	-.6	-.6	+.6

DAYTON WRIGHT TA-3

FIG. 6.

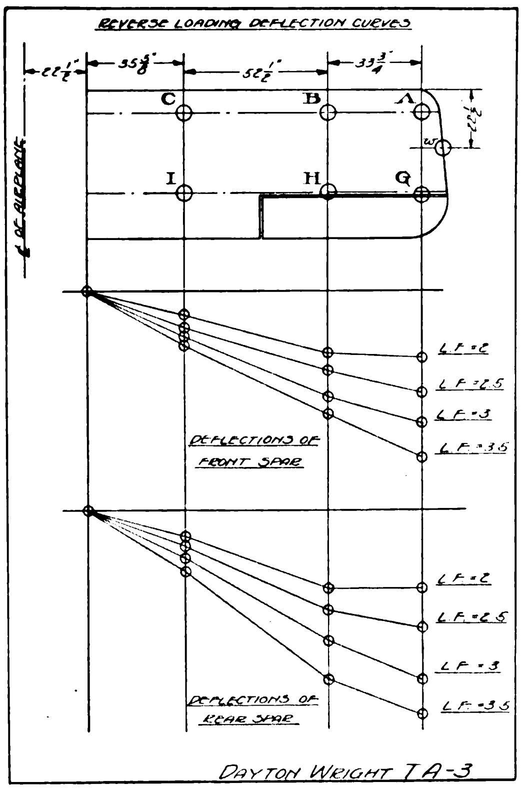
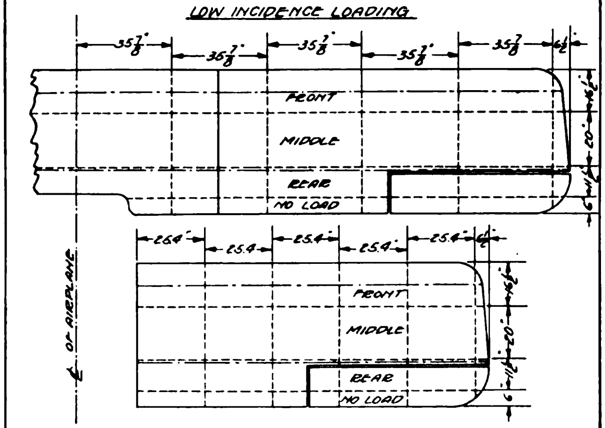


FIG. 7.

LOW INCIDENCE LOADING

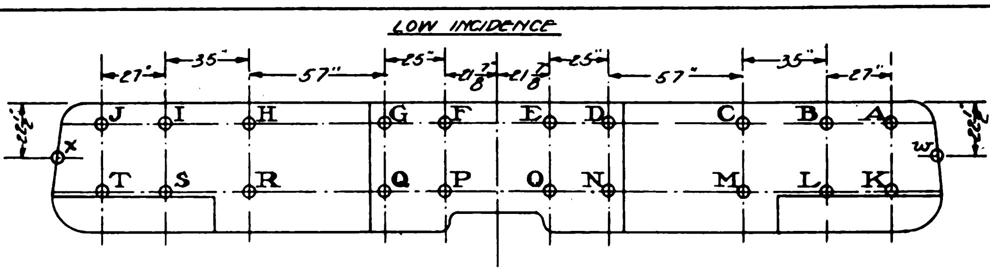


LOW INCIDENCE LOADING								
LOADING SCHEDULE FOR UPPER AND LOWER WINGS								
LOAD FACTOR	UPPER WING FRONT	UPPER WING MIDDLE	UPPER WING REAR	TOTAL LOAD	LOWER WING FRONT	LOWER WING MIDDLE	LOWER WING REAR	TOTAL LOAD
3	610	1230	610	2450	370	760	370	1500
4	830	1670	830	3330	500	1030	510	2040
4.5	940	1890	940	3770	570	1160	580	2310
5	1050	2110	1050	4210	640	1290	650	2580
5.5	1160	2330	1160	4650	710	1420	720	2850

SINCE THE SPAN OF BOTH UPPER AND LOWER WINGS ARE DIVIDED INTO TEN PARTS, THE LOAD PER SECTION MAY BE FOUND BY DIVIDING THE ABOVE VALUES BY TEN

DAYTON WRIGHT TA-3

FIG. 8.



LOAD FACTOR	FRONT SPAR RIGHT A	B	C	D	E	FRONT SPAR LEFT F	G	H	I	J	REAR SPAR RIGHT K	L	M	N	O	REAR SPAR LEFT P	Q	R	S	T	RETREAT LOWER w	x	RETREAT UPPER w	x
3	1.4	1.0	0.7	0.2	0.4	0.4	0	0.7	1.0	1.7	1.4	1.2	1.0	0	0.4	0.4	0.4	1.0	1.3	1.8	-.2	-.1	+.3	+.2
4	1.9	1.4	1.0	0.2	0.5	0.5	0	1.0	1.5	2.3	2.0	1.7	1.4	0.1	0.6	0.6	0.4	1.4	1.9	2.6	-.2	-.3	+.6	+.4
4.5	2.2	1.8	1.2	0.4	0.4	0.3	0.1	1.2	1.8	2.6	2.3	2.0	1.6	0.3	0.7	0.7	0.4	1.6	2.3	3.0	-.3	-.5	+.8	+.5
5	2.5	2.0	1.4	0.2	0.5	0.5	0.1	1.6	2.2	3.2	2.7	2.3	1.8	0.2	0.8	0.8	0.5	1.9	2.6	3.4	-.3	-.8	+.7	+.6
5.5	2.8	2.3	1.5	0.4	0.6	0.6	0.2	1.7	2.6	3.6	3.1	2.6	2.2	0.3	0.9	0.9	0.5	2.2	3.0	4.0	-.3	-1.0	+.7	+.5

TABLE OF UPPER WING SPAR DEFLECTIONS IN INCHES

DAYTON WRIGHT TA-3

FIG. 9.

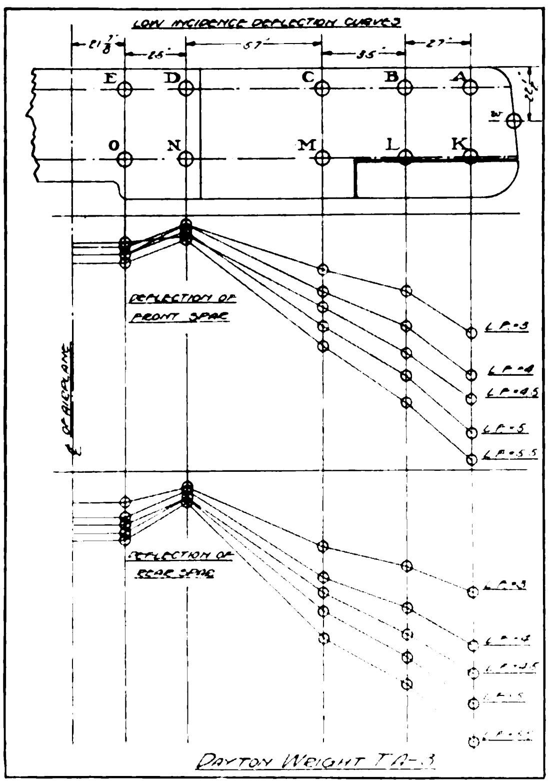
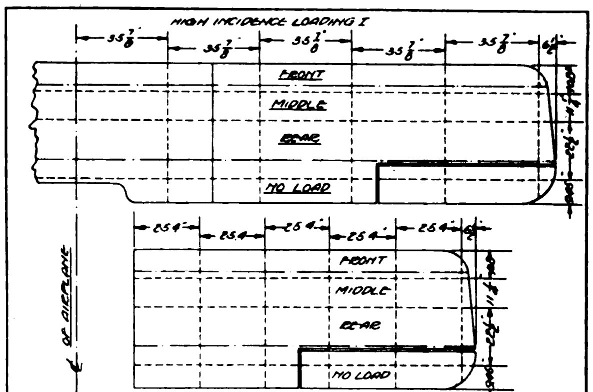


FIG. 10



HIGH INCIDENCE LOADING I								
LOADING SCHEDULE FOR UPPER AND LOWER WING								
LOAD FACTOR	UPPER WING FRONT	UPPER WING MIDDLE	UPPER WING REAR	TOTAL LOAD	LOWER WING FRONT	LOWER WING MIDDLE	LOWER WING REAR	TOTAL LOAD
3	1220	620	610	2450	750	380	370	1500
4	1660	840	830	3330	1020	520	500	2040
5	2100	1060	1050	4210	1290	660	630	2580
5.5	2320	1170	1160	4650	1430	730	690	2850
6	FAILURE OF FRONT UPPER RIGHT SPAR AT STRUT ATTACHMENT							

TOTAL LOAD SUPPORTED BY WINGS — — — — 7500#

SINCE THE SPAN OF BOTH UPPER AND LOWER WINGS ARE DIVIDED INTO TEN PARTS, THE LOAD PER SECTION MAY BE FOUND BY DIVIDING THE ABOVE VALUES BY TEN.

DAYTON WRIGHT TA-3

FIG. 11.

HIGH INCIDENCE I

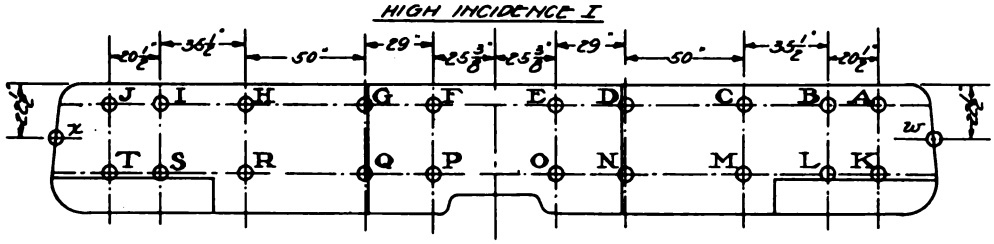


TABLE OF UPPER WING SPAR DEFLECTIONS IN INCHES																								
LOAD FACTOR	FRONT SPAR										REAR SPAR										RETREAT			
	RIGHT					LEFT					RIGHT					LEFT					LOWER		UPPER	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	w	x	w	x
4	1.9	1.6	1.2	0.5	0.8	0.7	0.6	1.2	1.4	1.8	1.8	0.6	1.0	0.2	0.3	0.4	0.2	0.8	1.2	1.8	+.2	+.1	+.5	+.7
5	2.4	1.9	1.6	0.6	0.9	1.0	0.8	1.5	1.9	2.5	2.3	1.0	1.2	0.3	0.3	0.4	0.3	1.0	1.8	2.4	+.3	+.3	+.8	+.8
5.5	2.8	2.1	1.8	0.6	1.1	1.0	0.7	1.9	2.2	2.9	2.6	1.1	1.4	0.2	0.4	0.5	0.3	1.2	1.9	2.6	+.3	+.3	+.6	+.8
6	THE FRONT RIGHT UPPER SPAR FAILED AT THE POINT OF STRUT CONNECTION BY SPLITTING																							

NOTE: THE SPAR SPLIT LONGITUDINALLY AND THE OFFSET FORCES CAUSED BY ECCENTRIC STRUT AND WIRE CONNECTIONS ROTATED THE LOWER HALF OF THE SPAR AXIALLY CLOCKWISE AS SEEN FROM THE FUSELAGE.

DAYTON WRIGHT TA-3

FIG. 12.

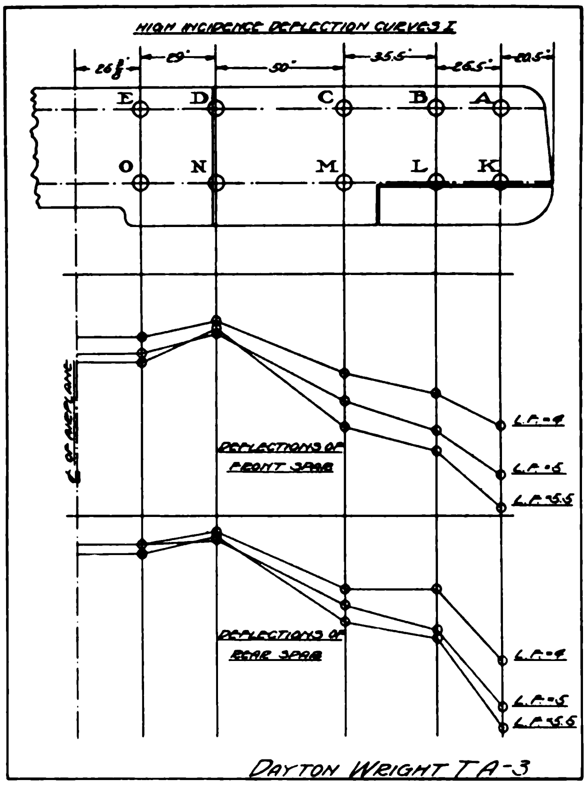


FIG. 13.

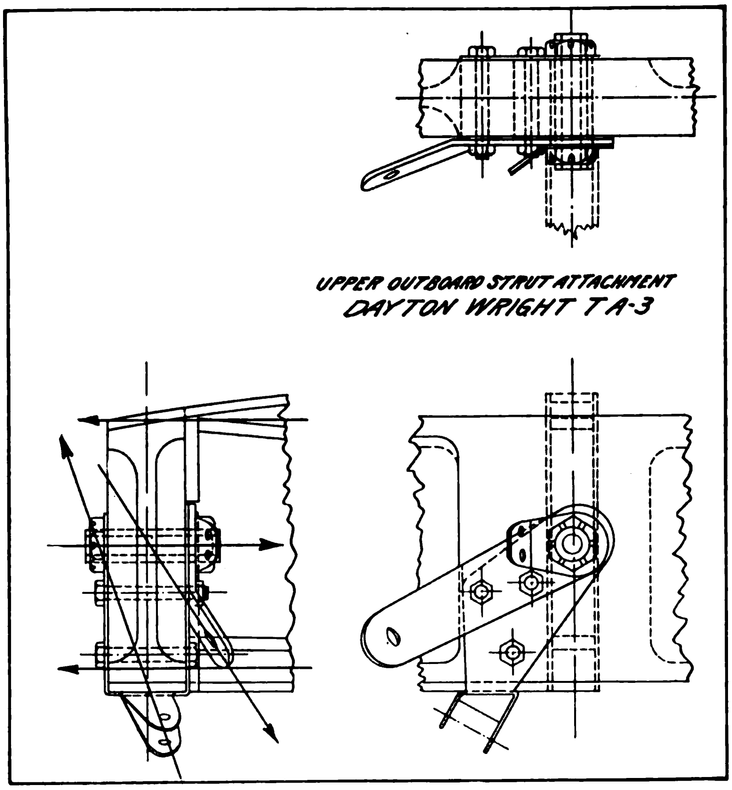
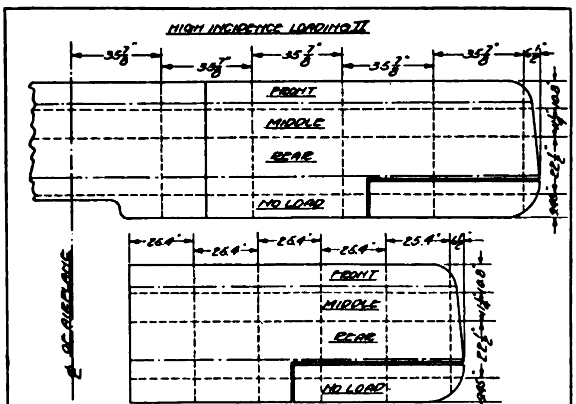


Fig. 14.



HIGH INCIDENCE LOADING II								
LOADING SCHEDULE FOR UPPER AND LOWER WINGS								
LOAD FACTOR	UPPER WING			TOTAL LOAD	LOWER WING			TOTAL LOAD
	FRONT	MIDDLE	REAR		FRONT	MIDDLE	REAR	
4	1660	840	830	3330	1020	520	500	2040
5	2100	1060	1050	4210	1290	660	630	2580
5.5	2320	1170	1160	4650	1430	730	690	2850
6	2540	1280	1270	5090	1570	800	750	3120
6.5	2760	1390	1380	5530	1710	870	810	3390
7	2980	1500	1490	5970	1850	940	870	3660
7.5	3200	1610	1600	6410	1990	1010	930	3930
8	FAILURE OF LOWER LEFT REAR WING SPAR ATTACHMENT FITTING							

TOTAL LOAD SUPPORTED BY WINGS — — — 10,340#

SINCE THE SPAN OF BOTH UPPER AND LOWER WINGS ARE DIVIDED INTO TEN SECTIONS, THE LOAD PER SECTION MAY BE FOUND BY DIVIDING ABOVE VALUES BY TEN.

DAYTON WRIGHT TA-3

Fig. 15.

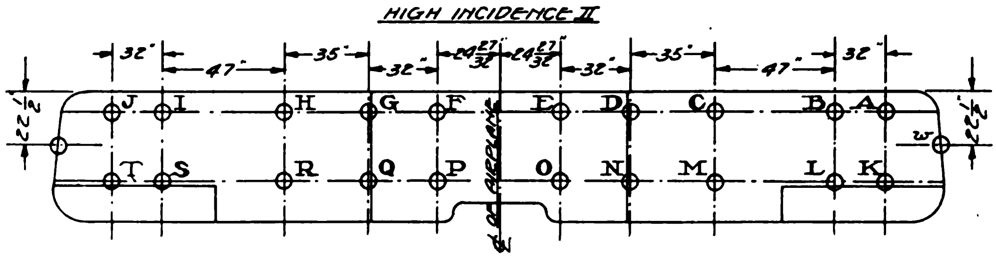


TABLE OF UPPER WING SPAR DEFLECTIONS IN INCHES																								
LOAD FACTOR	FRONT SPAR										REAR SPAR										RETREAT			
	RIGHT					LEFT					RIGHT					LEFT					LOWER		UPPER	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	w	x	w	x
4	2.5	1.0	0.6	0.3	0.6	0.7	0.4	1.2	1.7	2.1	1.4	0.9	0.5	0.1	0.2	0.6	0.2	1.1	1.6	2.2	+.2	+.5	+.4	+.1
5	2.9	1.4	0.9	0.3	0.7	0.8	0.5	1.5	2.1	2.7	1.9	1.2	0.6	0.0	0.3	0.6	0.3	1.3	2.1	2.7	.2	.6	.4	.3
5.5	3.2	1.6	1.0	0.5	0.8	0.9	0.5	1.6	2.2	3.0	2.1	1.6	0.7	0.1	0.3	0.6	0.3	1.4	2.3	2.9	.3	.6	.4	.1
6	3.6	1.9	1.2	0.4	0.9	0.9	0.5	1.7	2.6	3.4	2.4	1.7	0.9	0.1	0.4	0.7	0.3	1.6	2.5	3.2	.3	.5	.4	.2
6.5	3.8	2.2	1.4	0.5	1.0	1.1	0.4	1.9	2.9	3.9	2.8	2.0	1.1	0.1	0.4	0.6	0.3	1.7	2.8	3.6	2	.7	.4	.4
7	4.8	2.8	1.7	0.6	1.1	1.2	0.6	2.2	3.4	4.8	3.5	2.4	1.3	0.2	0.4	0.7	0.4	1.9	3.3	4.3	2	.5	.7	.4
7.5	5.6	3.6	2.0	0.6	1.2	1.2	0.6	2.8	4.4	6.0	4.4	3.1	1.6	0.2	0.5	0.8	0.4	2.2	4.2	5.4	0	.5	.6	.5
8	THE LOWER LEFT REAR WING SPAR ATTACHMENT FITTING OF THE FUSELAGE TORE OUT.																							

DAYTON WRIGHT TA-3

FIG. 16.

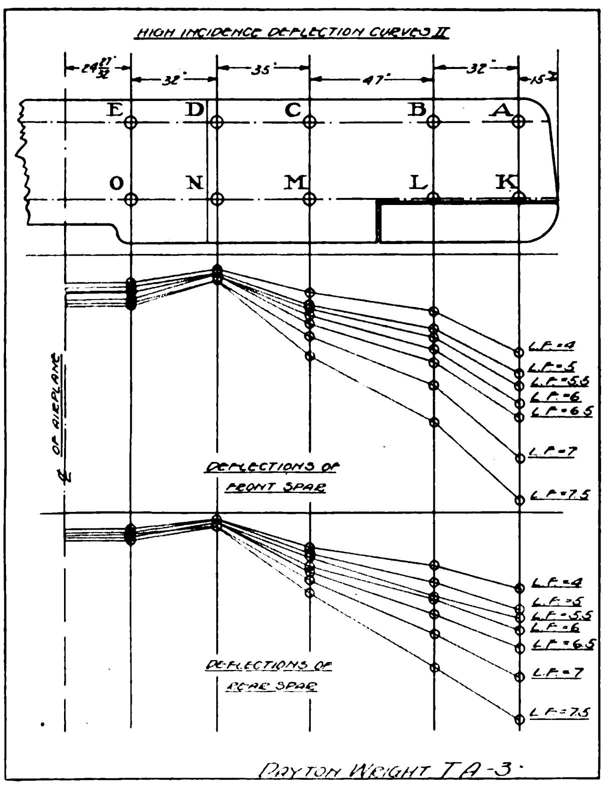


FIG. 17.

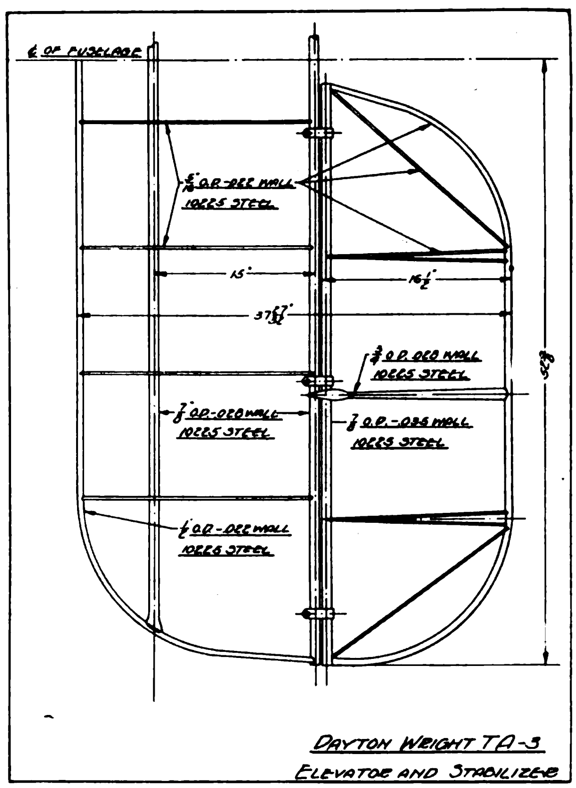
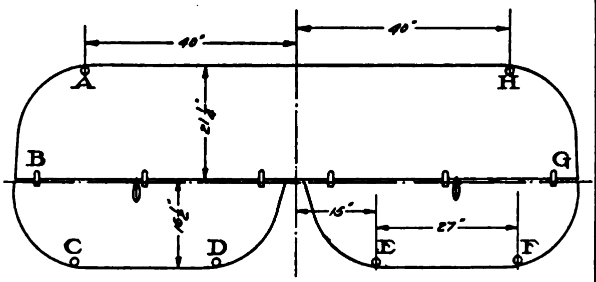


FIG. 18.



AREA OF STABILIZER ——— 14.7□'
AREA OF ELEVATOR ——— 10.2□'
TOTAL HORIZONTAL TAIL AREA —— 24.9□'

RESULTS OF STABILIZER AND ELEVATOR TEST											
LOADING			PULL ON	DEFLECTIONS							
# □'	STAB.	ELEV.	STICK	A	B	C	D	E	F	G	H
5	85	42	15	0	.1	.1	0	.1	.2	0	.1
10	170	84	25	0	.1	.4	.5	.6	.5	0	.1
15	256	126	45	0	.1	.8	1.0	1.0	1.0	0	.2
20	340	168	55	0	.1	1.3	1.4	1.5	1.3	0	.2
22.5	382	189	65	.1	.2	1.5	1.7	1.8	1.7	0	.2
25	425	210	70	.1	.2	1.7	1.9	2.2	1.8	0	.2
27.5	467	231	80	.1	.2	2.0	2.1	2.8	2.4	0	.2
30	510	252	90	.1	.3	2.3	2.5	2.4	2.9	0	.2
32.5	552	273	100	.1	.3	2.7	2.9	3.9	3.3	0	.2
35	595	294	110	.1	.3	3.3	3.7	4.5	3.9	.1	.2
37.5	637	315	NO FAILURE - PERMANENT WARP IN TRAILING EDGE.								
40	670	336	"	"		"		"	"	"	"

DAYTON WRIGHT TA-3

FIG. 19.

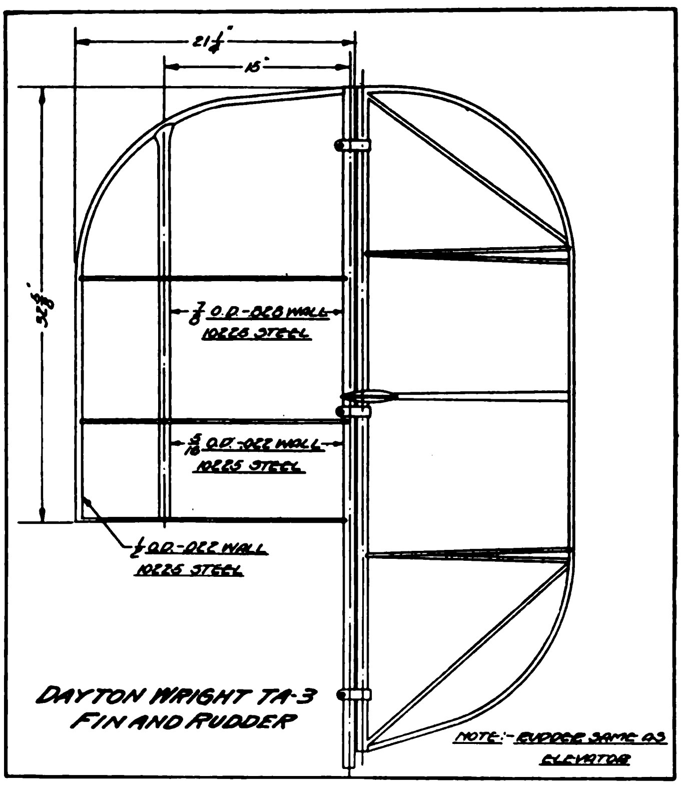
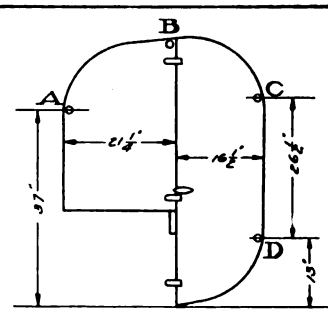


FIG. 20.



AREA OF FIN ——— 4.35□'
AREA OF RUDDER ——— 5.10□'
TOTAL VERTICAL TAIL AREA —— 9.45□'

RESULTS OF FIN AND RUDDER TEST							
LOADING			PULL ON STICK	DEFLECTIONS			
#/□'	FIN	RUDDER		A	B	C	D
5	26.5	20.75	15	.1	.1	.2	.2
10	53	40.6	30	.1	.1	.4	.4
15	79.5	62.3	40	.1	.2	.7	.7
20	106	83	55	.2	.2	1.2	1.2
22.5	119	93	65	.2	.2	1.1	1.1
25	132.5	104	75	.3	.3	1.5	1.7
27.5	146	114	90	.2	.3	1.7	2.0
30	159	125	100	.3	.3	1.9	2.1
—	LOAD CARRIED TO 60# □' IN 2.5# STEPS						
60	NO FAILURE - PERMANENT WARP IN T.E.						

DAYTON WRIGHT TA-3

FIG. 21.

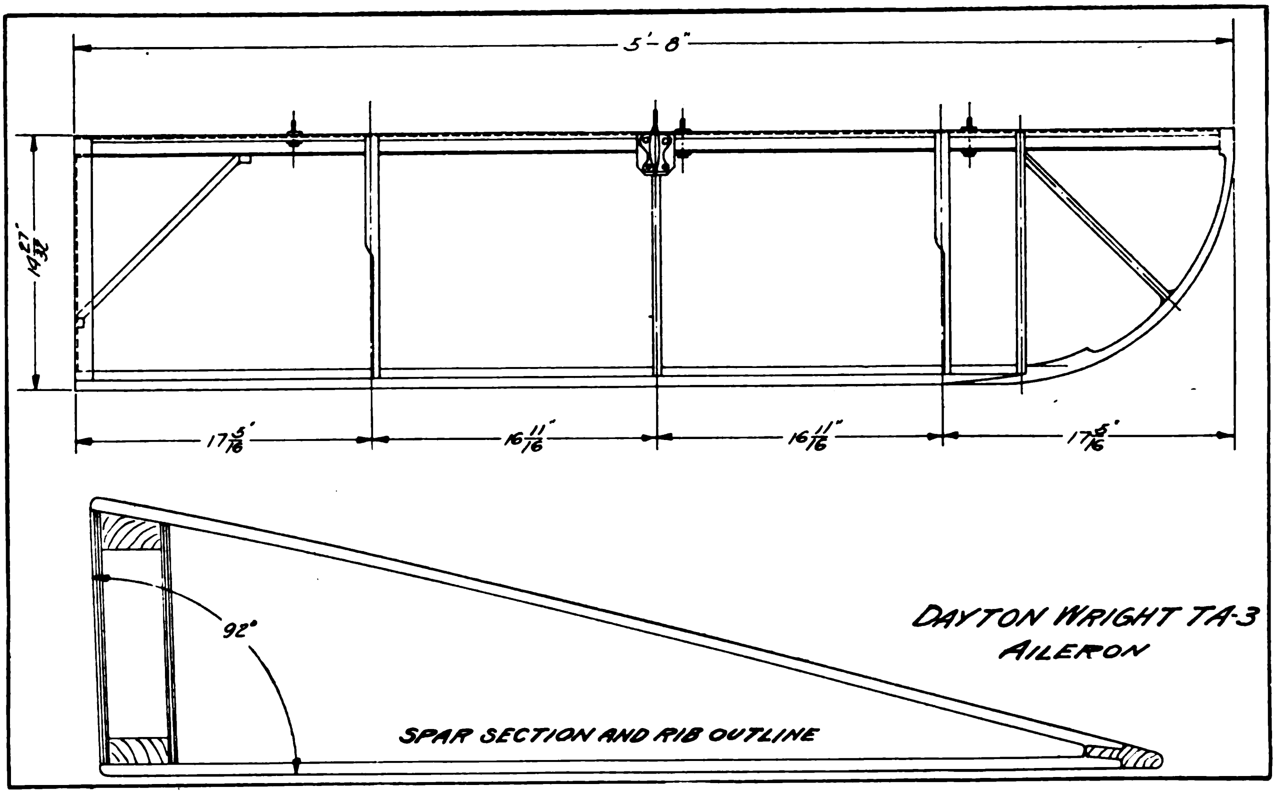
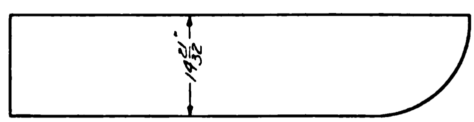


FIG. 22.



AREA OF AILERON —————— 6.75 □'

RESULTS OF AILERON TEST			
LOADING		PULL ON STICK	REMARKS
#/□'	TOTAL		
5	34	20	
10	68	45	EXCESSIVE DEFLECTION.
15	102	80	
20	136		LINK CONNECTING CONTROL
			STICKS BUCKLED.

NOTE:
AFTER THE TEST, THE TRIANGULAR BELL CRANK LEVER SUPPORT WAS FOUND TO HAVE PULLED AWAY FROM THE SPAR.

DAYTON WRIGHT TA.-3

FIG. 23.

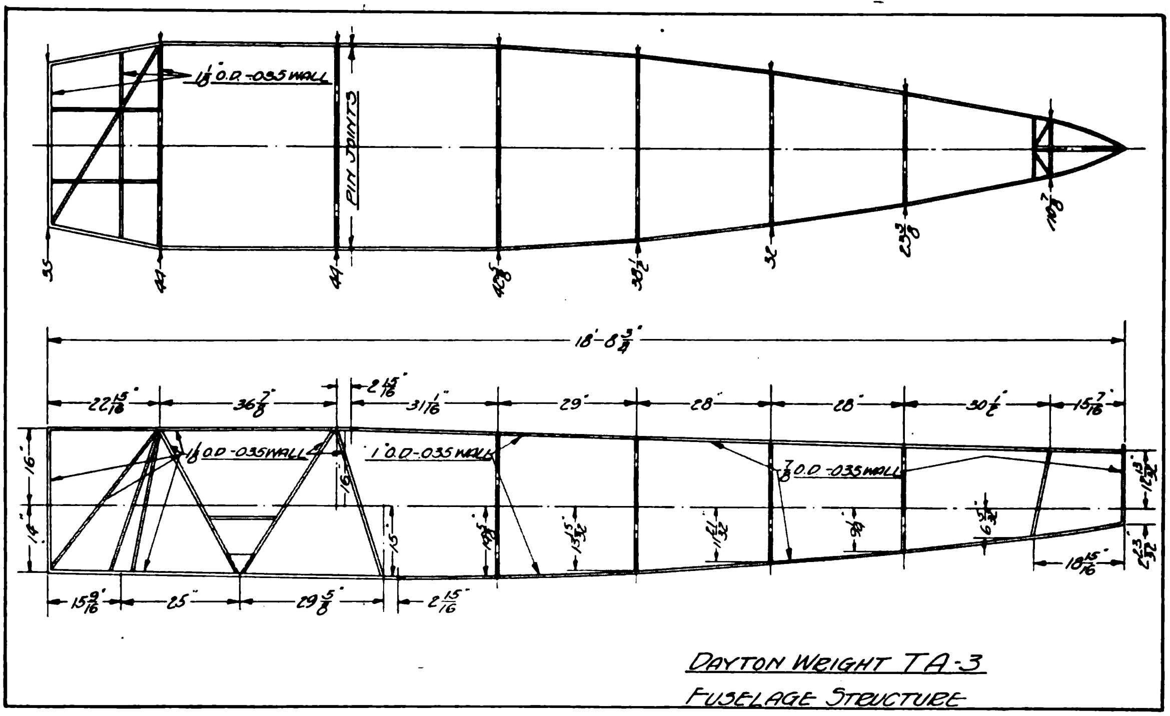
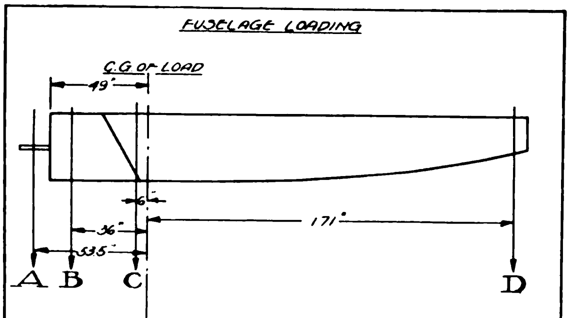


FIG. 24.



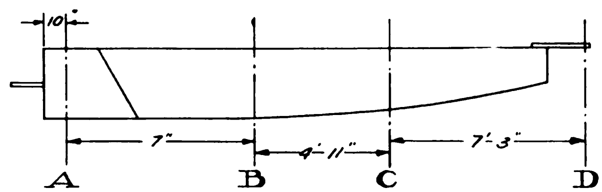
FUSELAGE LOADING SCHEDULE				
LF	A	B	C	D
2	650	300	1104	363
3	974	484	1686	565
4	1298	668	2268	767
5	1722	852	2850	969
5.5	1884	944	3141	1070
6	2046	1036	3432	1171
6.5	2208	1128	3723	1272
7	2370	1220	4014	1373
10	FAILURE OF LOWER R H LONGERON			

TOTAL LOAD SUPPORTED BY FUSELAGE — 12753#

DAYTON WRIGHT TA-3

FIG. 25.

FUSELAGE DEFLECTIONS

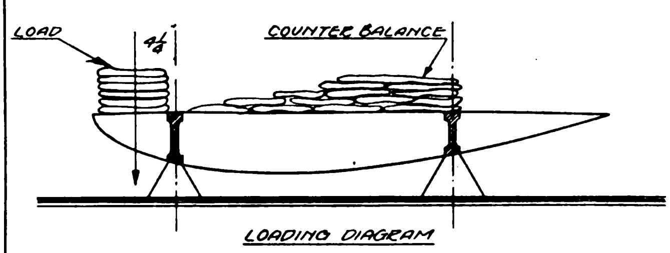


FUSELAGE DEFLECTIONS IN INCHES					
L.F.	A	B	C	D	REMARKS
2	0.3	0.5	0.8	1.5	
3	0.5	0.6	1.0	1.7	
4	0.7	0.8	1.2	2.2	
5	0.7	1.0	1.5	2.9	
5.5	0.7	1.0	1.9	3.2	
6	0.7	1.1	2.1	3.7	
6.5	0.7	1.2	2.1	3.9	
7	0.7	1.3	2.3	4.1	
10	FAILURE OF LOWER RIGHT LONGERON.				

DAYTON WRIGHT T A-3

FIG. 26.

LEADING EDGE TEST



LOAD SUPPORTED BY LEADING EDGE ———— 950#

LEADING EDGE SHEARED OFF AT THE FACE OF THE FRONT SPAR

WEIGHT OF AIRPLANE ———— 1738#

LOAD CARRIED BY UPPER WING = 1738 X .62 —— 1077#

LOAD ON UPPER WING PER FOOT RUN = 1077 ÷ 31 —— 35#

LOAD ON LEADING EDGE FOR FACTOR OF ONE = 35 ÷ 2 —— 18#

LOAD PER FOOT CARRIED BY THE LEADING EDGE =

950 ÷ 6 —— 158.3

FACTOR AT WHICH LEADING EDGE FAILED = 158.3 ÷ 18 —— 9

DAYTON WRIGHT T A-3

FIG. 27.

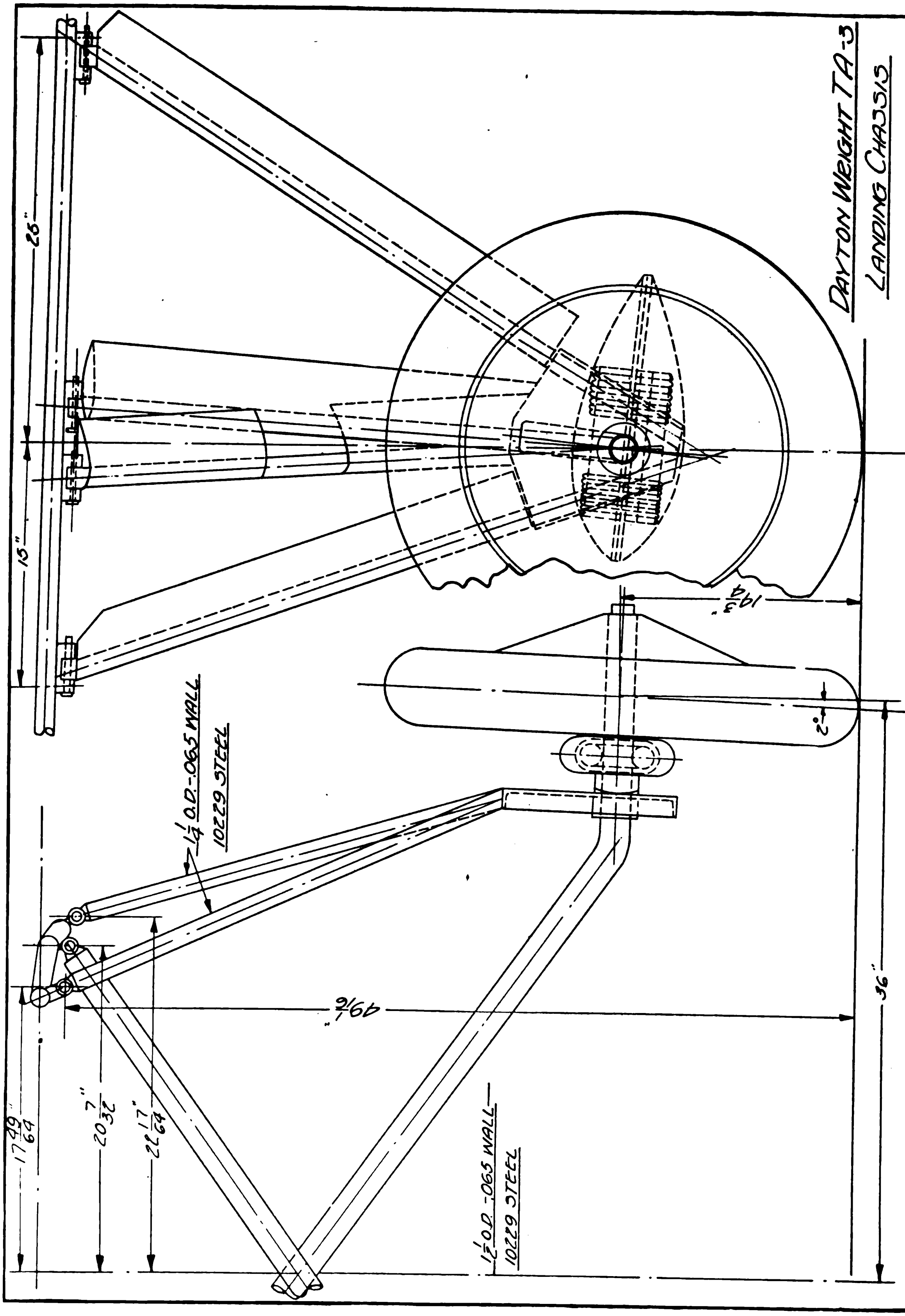
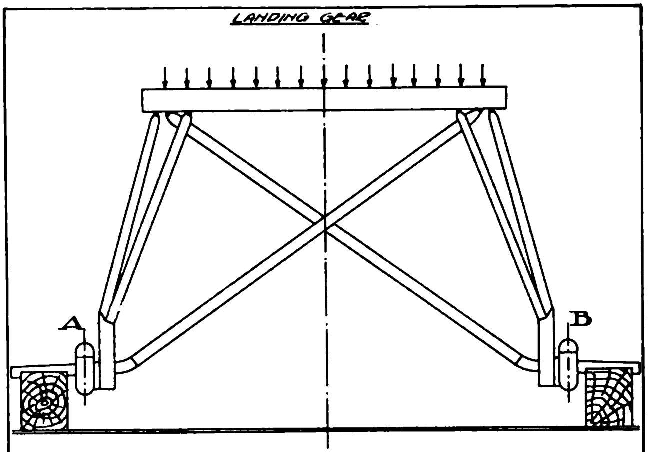

DAYTON WRIGHT TA-3
LANDING CHASSIS
25"
15"
$1\frac{1}{4}$ O.D. -.065 WALL
10229 STEEL
$1\frac{1}{2}$ O.D. -.065 WALL
10229 STEEL
36"
2"

Fig. 28.



RESULTS OF LANDING GEAR TEST				
LOAD FACTOR	TOTAL LOAD #	DEFLECTIONS A	DEFLECTIONS B	REMARKS
2	3476	0.19	0.69	
3	5214	0.50	1.00	BOW IN LEFT REAR STRUT AND IN AXLES
4	6952	0.94	1.19	" " " " " " " "
5	8690	1.69	2.13	" " " " " " " "
5.5	9559	—	—	PERMANENT SET IN LEFT REAR STRUT.
6	10428	—	—	LEFT REAR STRUT BUCKLED.

NOTE: THE AXLES MOVED LATERALLY IN THE BLOCKS 1¼"

DAYTON WRIGHT TA-3

FIG. 29.

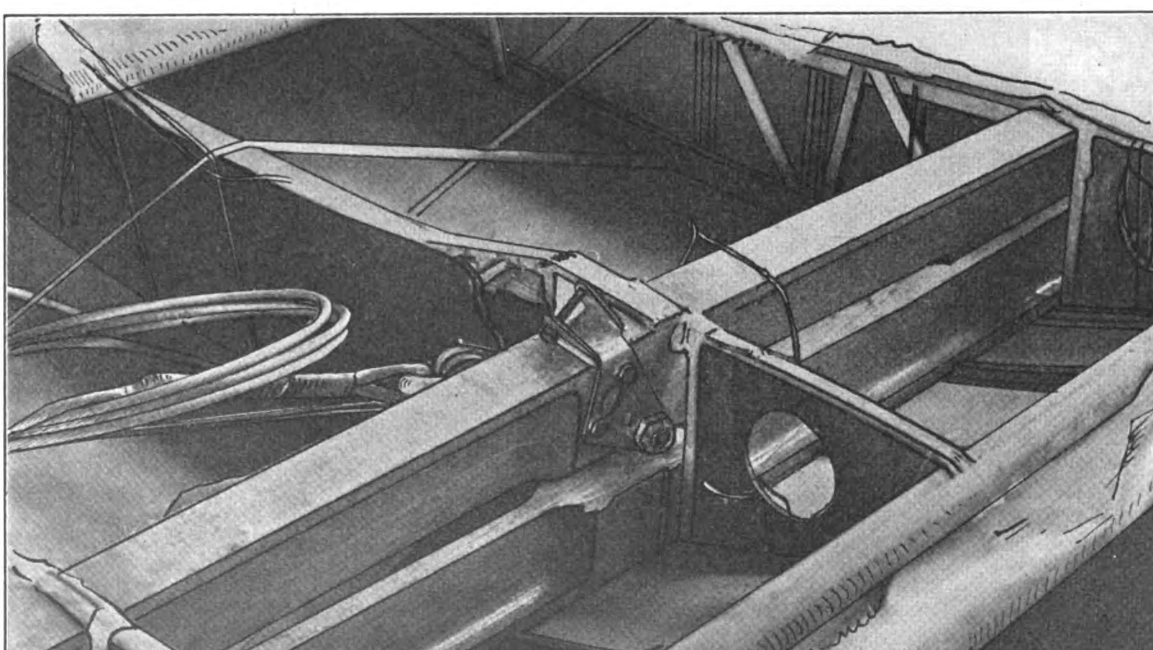


FIG. 30.

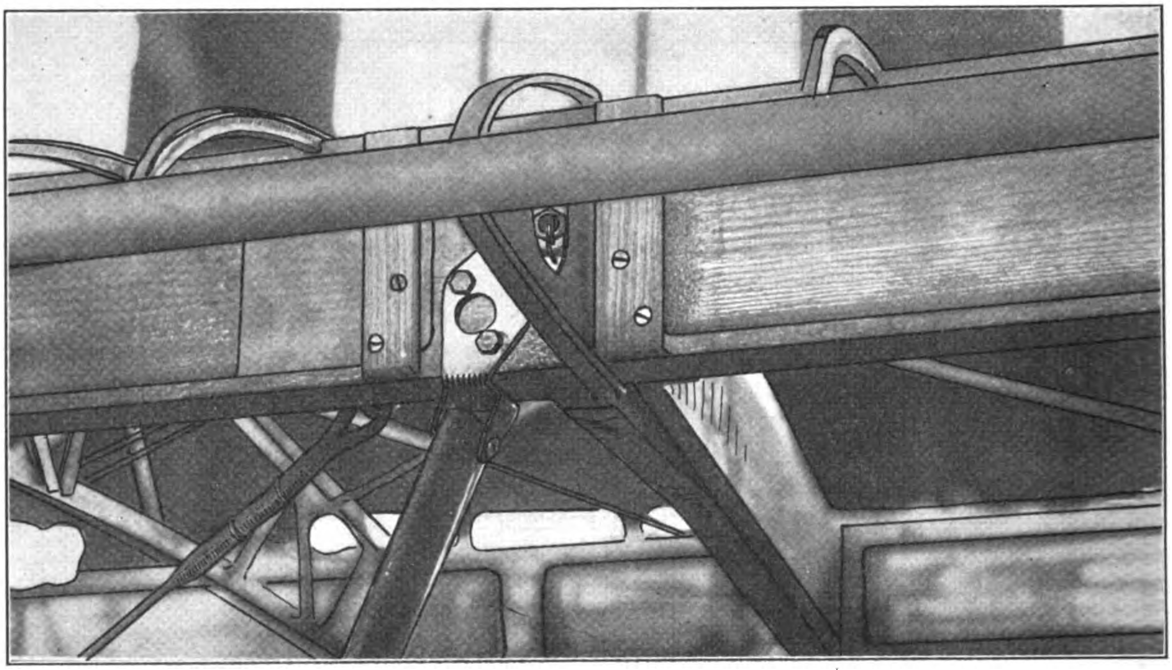


Fig. 31.

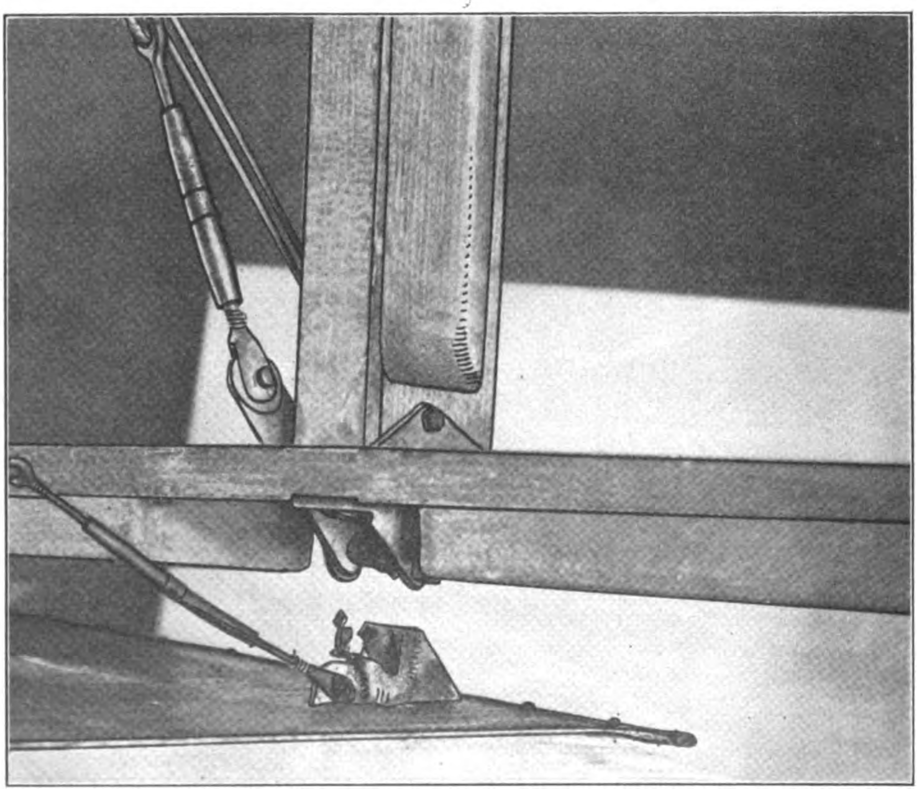


Fig. 32.

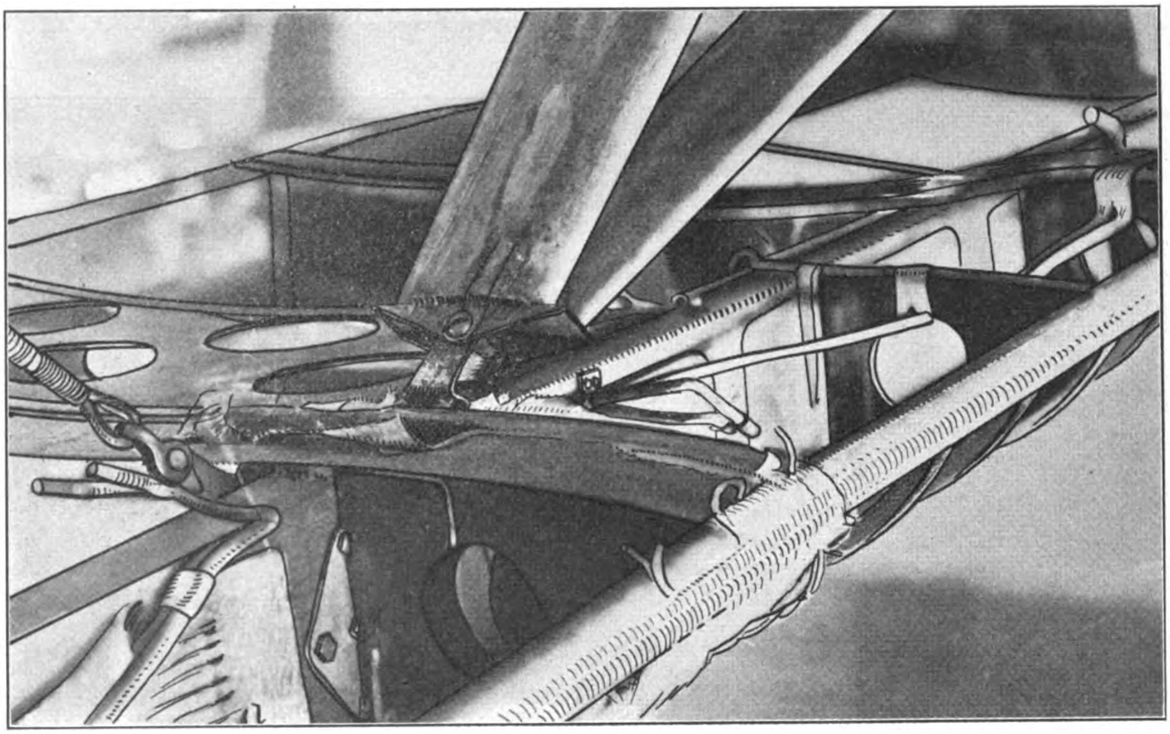


Fig. 33.

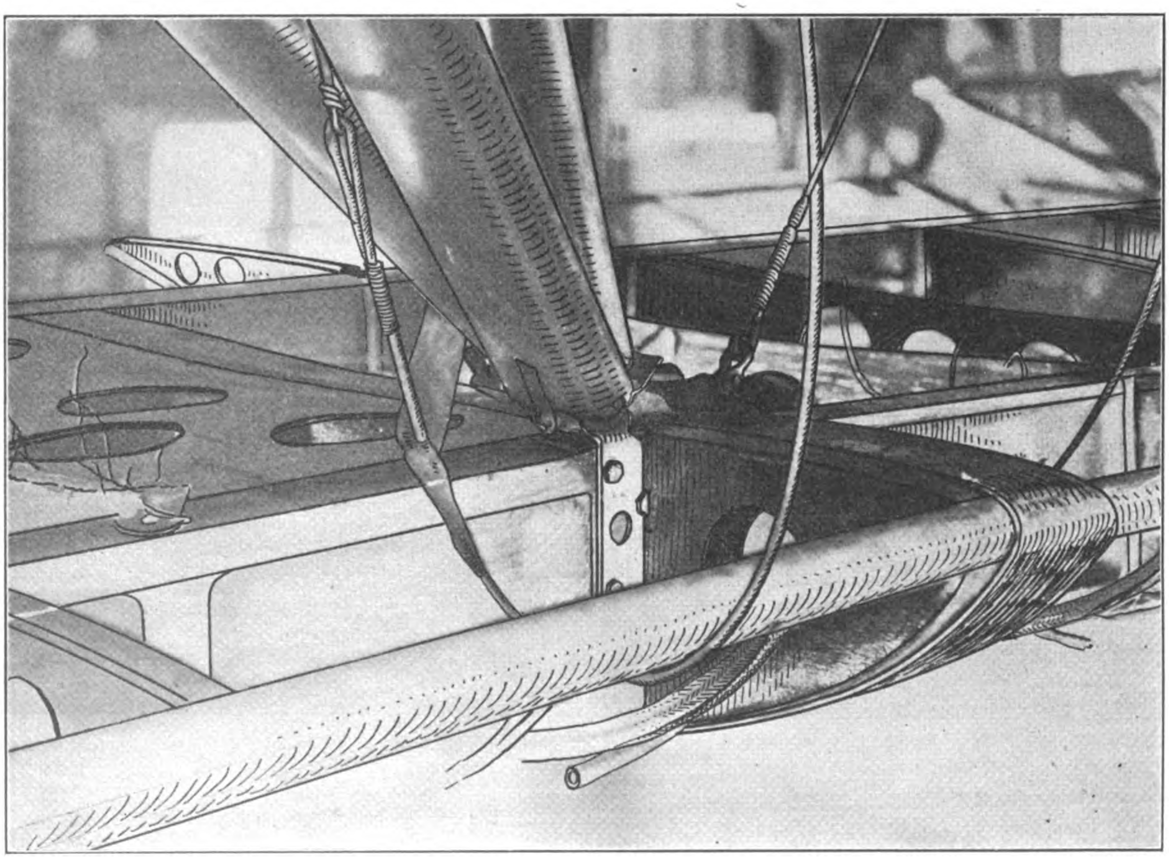


Fig. 34.

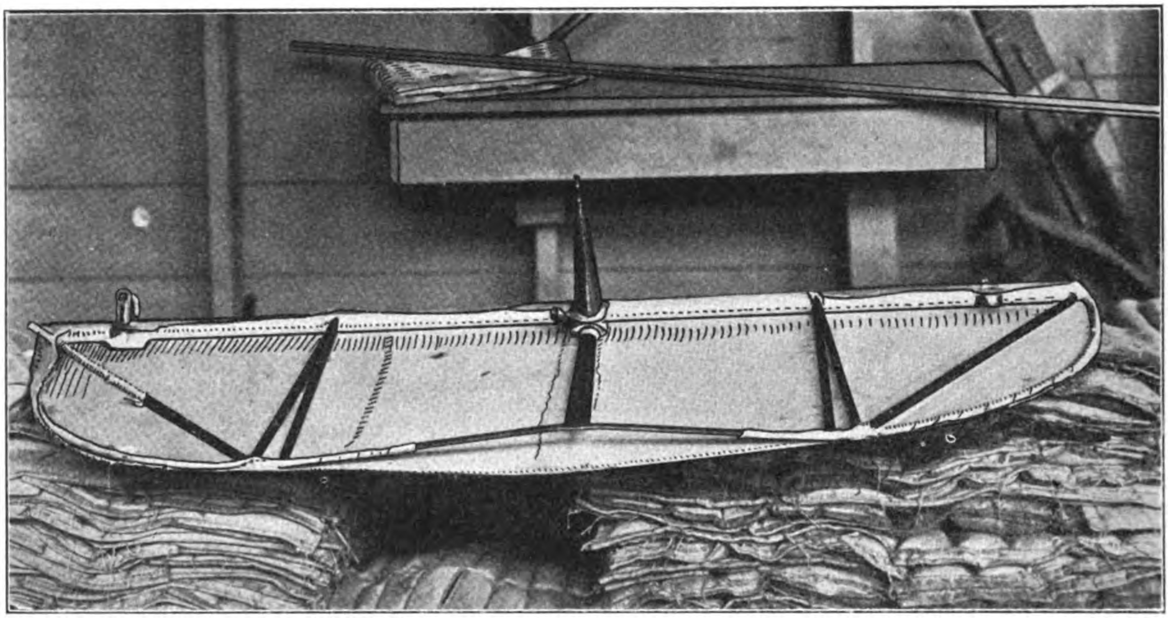


Fig. 35.

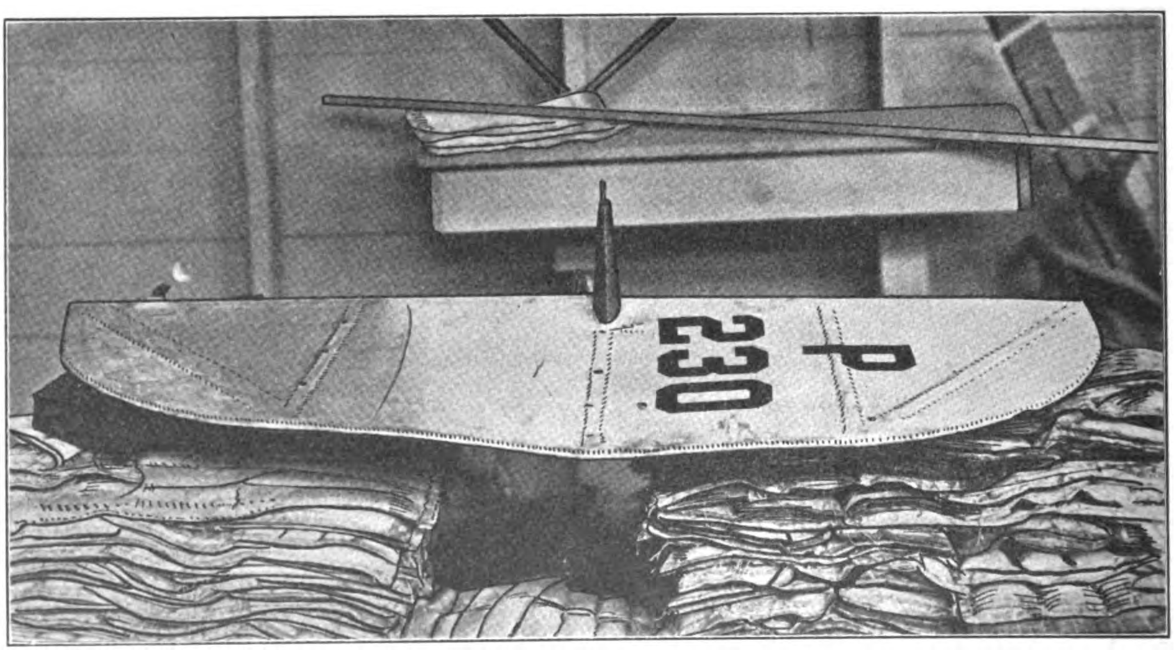


Fig. 36.

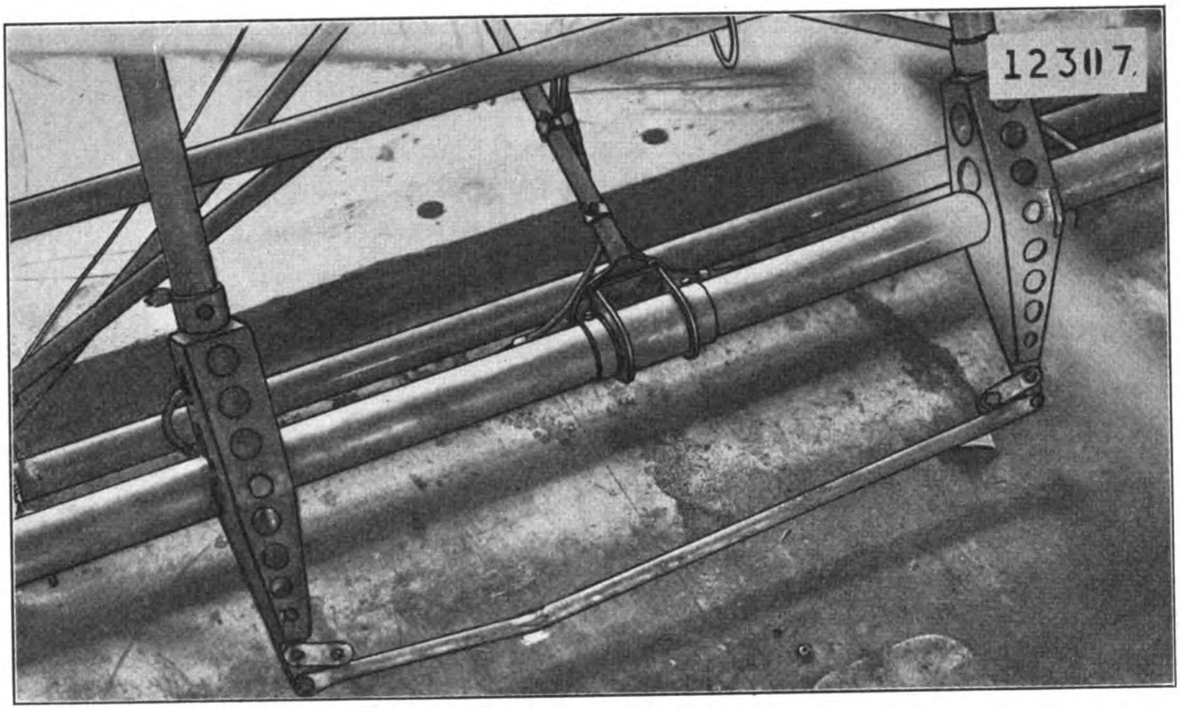


FIG. 37.

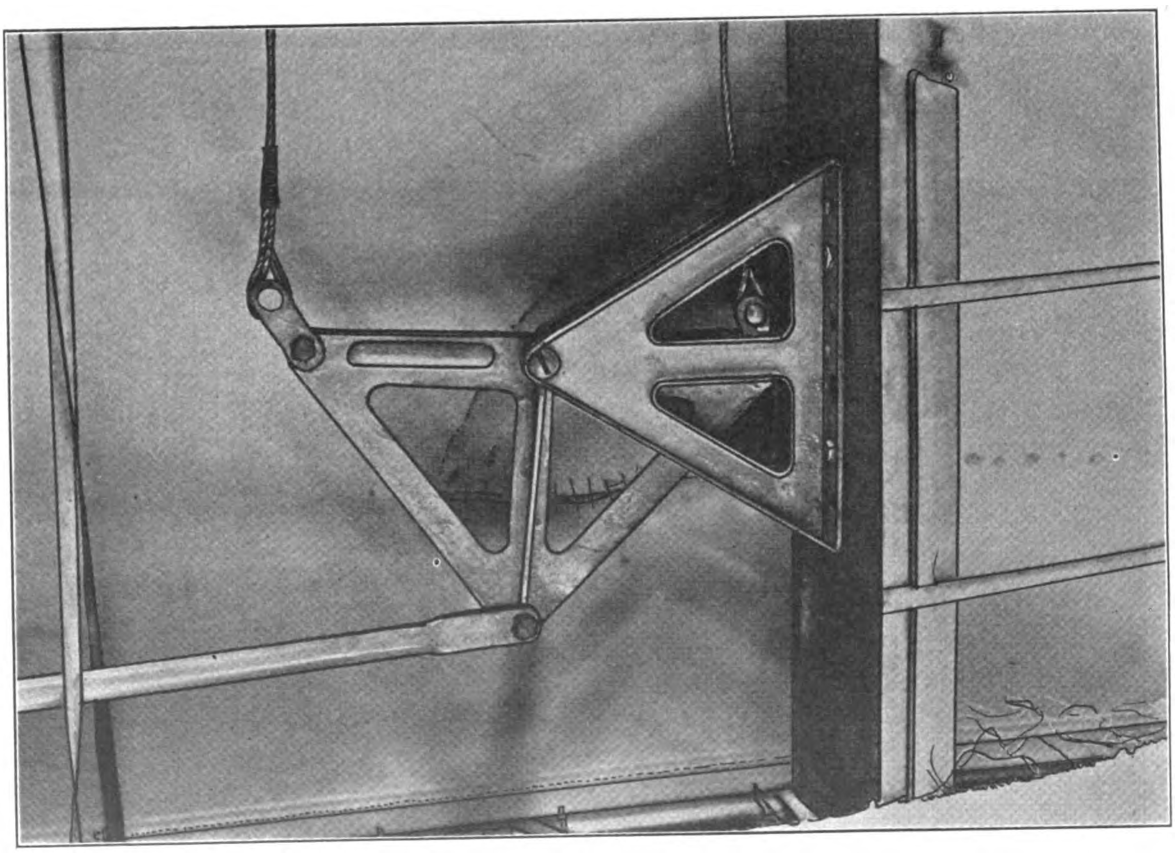


FIG. 38.

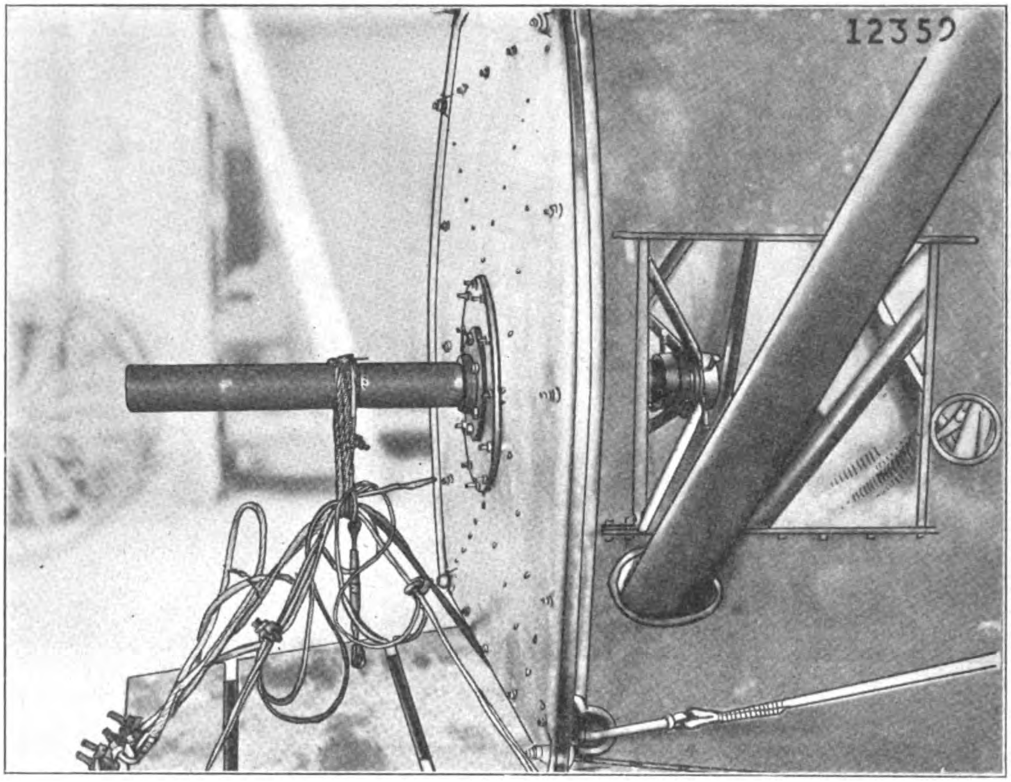


Fig. 39.

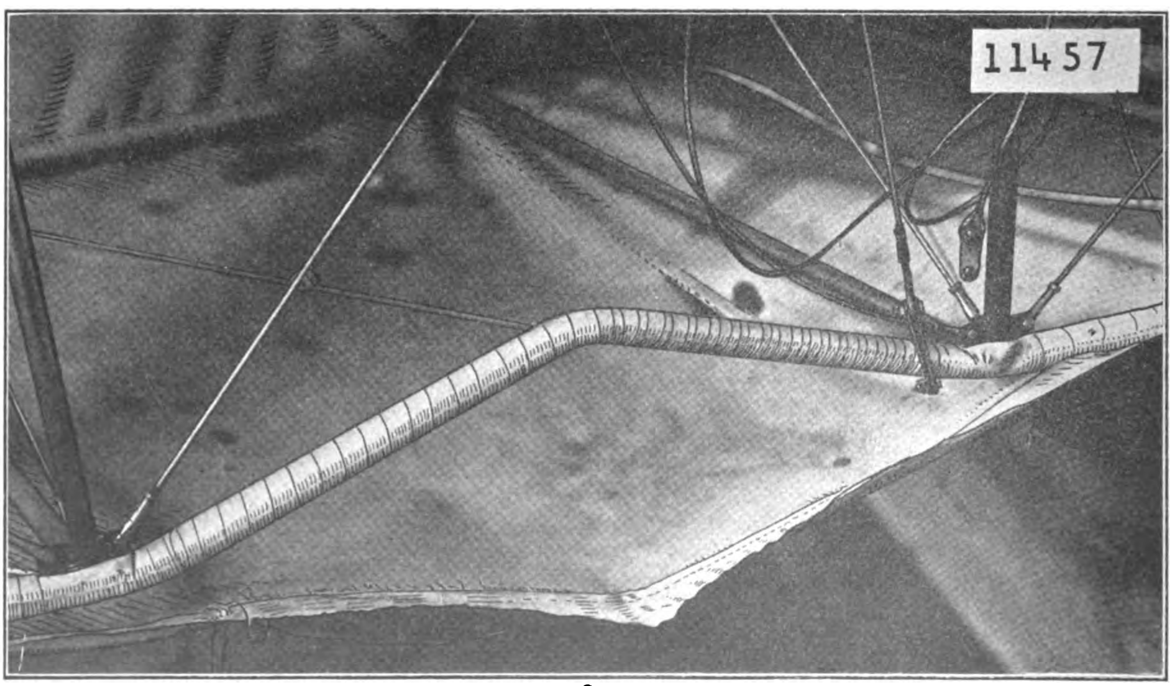


Fig. 40

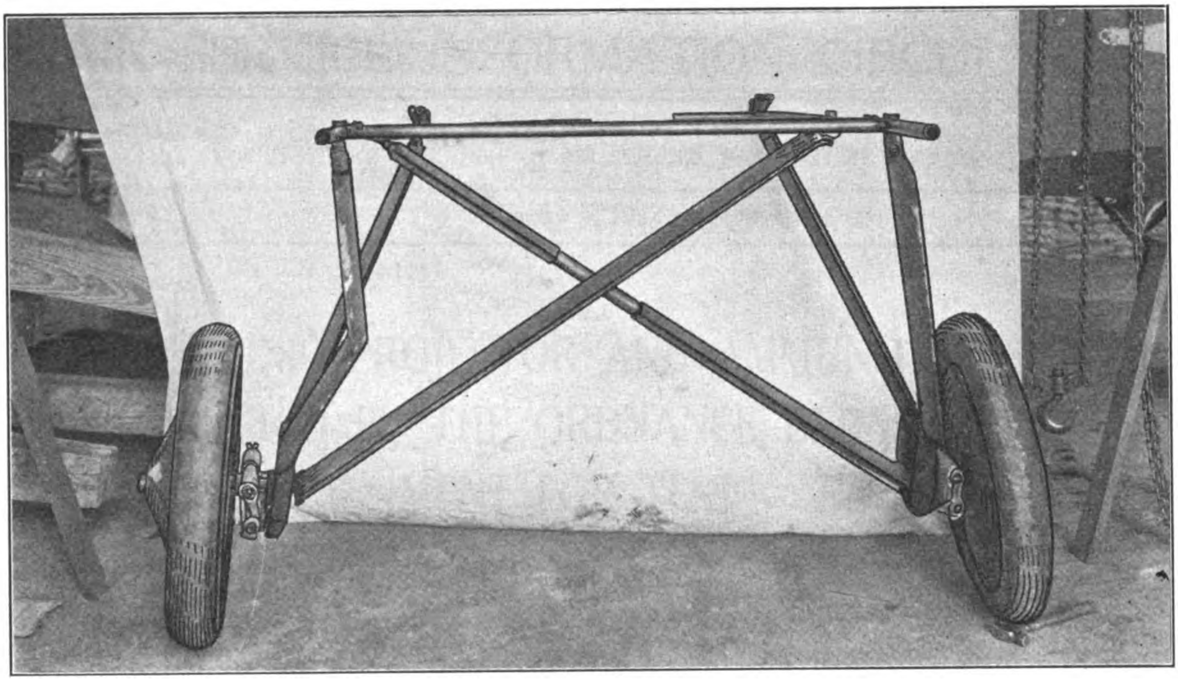


Fig. 41.

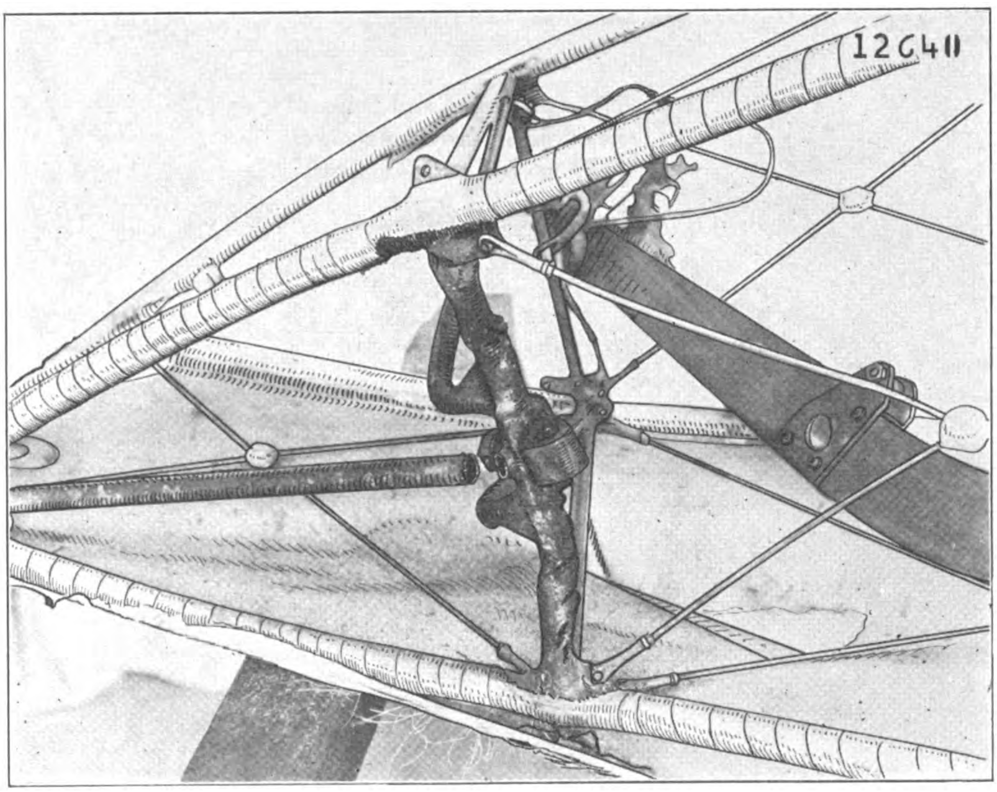


Fig. 42.

File D 70/64 *McCOOK FIELD REPORT, SERIAL No. 1990*

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV December 1, 1922 No. 389

PYROTECHNIC PROJECTOR AND AMMUNITION SUBMITTED BY THE ORDNANCE DEPARTMENT FOR TEST

(ARMAMENT SECTION REPORT)

▽

Prepared by Charles Leigh Paulus
Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 3, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

PYROTECHNIC PROJECTOR AND AMMUNITION SUBMITTED BY THE ORDNANCE DEPARMENT FOR TEST.

OBJECT.

To test pyrotechnic projector and ammunition submitted by the Ordnance Department. This test to include installation of the projector and ground and air test of the ammunition.

RECOMMENDATIONS.

Due to the fact that all tests described were satisfactory, it is recommended that this mechanism be used as a standard means of projecting signals for use upon aircraft. It is further recommended that the signals tested are entirely satisfactory for use in the Air Service at the present time.

CONCLUSIONS.

It is concluded that the pyrotechnic projector as submitted by the Ordnance Department should be adopted for standard use in the Air Service. It is further concluded that the ammunition as furnished by the Ordnance Department is entirely satisfactory and should be adopted for standard use.

DESCRIPTION.

Figure 1 shows a top quarter view of the pyrotechnic projector as submitted for test. This figure clearly demonstrates the rugged inexpensive construction used throughout the mechanism. Figure 2 shows the side view of the pyrotechnic projector loaded. This view of the mechanism shows the dovetail slide principle used in loading the signal and ejecting the empty shell. Figure 3 shows a top quarter view of the pyrotechnic projector with the slide in the open position. This figure demonstrates the possibility of loading, firing, and ejecting by the use of one hand. Figure 4 shows a bottom view of the mechanism. This figure shows the retaining plungers, the cartridge maintaining block, and the ejection mechanism. Figure 5 shows the ammunition submitted by the Ordnance Department for test. The outer diameters are knurled in such a way as to permit the various signals to be recognized through the sense of touch. The end of the ammunition is plainly marked to designate, by sight, the signal encased. These markings are shown in the figure and are, reading from left to right, "Y" yellow smoke, "RP" red parachute, "GC" green chain, and "WS" white star. Figure 6 shows the yellow-smoke signal disassembled. It will be observed that a small parachute is attached to the smoke signal by use of a short length steel cable. This part of the mechanism is packed in the outer portion of the aluminum container and maintained in place by use of a felt washer, cardboard disk, and pressed steel cover. The opposite end of the mechanism contains the powder charge which propels the above-mentioned unit clear of the airplane, and is maintained in position by the rimmed member which contains the primer cap. Figure 7 shows the white-star signal disassembled. This mechanism contains the same firing unit described above. It contains a series of metal containers into which is compressed a brilliant burning powder mixture. Figure 8 shows a green-chain signal disassembled. This mechanism contains a parachute on the bottom of which is maintained a series of green burning powder charges.

TEST.

The pyrotechnic projector as shown in Figures 8, 1, 3, and 4, was mounted on DH-4B and XB-1A airplanes. Both of these airplanes were active, during night flying tests of electric equipment, over a considerable period of time, and the ammunition described was used for signaling purposes. This arrangement permitted a practical duplication of service conditions; and although the projector was operated a great many times by varied personnel, no malfunction was encountered.

The yellow-smoke signals as shown in Figure 8, were fired in daylight and were found to burn approximately 30 seconds. These tests were observed from the ground, and it was found that the signals were visible for approximately 7 miles.

The white-star signals were tested during night flight tests, and these signals were found to burn approximately 5 seconds and to give a very brilliant penetrating white light.

The green-chain signals shown in Figure 8 were tested at night. These signals burn approximately 30 seconds and were clearly visible at an altitude of 5,000 feet.

The red-parachute signal, which is similar in construction to the yellow-smoke signal shown in Figure 6, was tested during night flight tests. These signals burn approximately 30 seconds and were visible from the ground at an altitude of 5,000 feet.

Although 200 rounds of the pyrotechnic projector ammunition described were fired during these tests, no malfunction which could be traced to the ammunition was encountered.

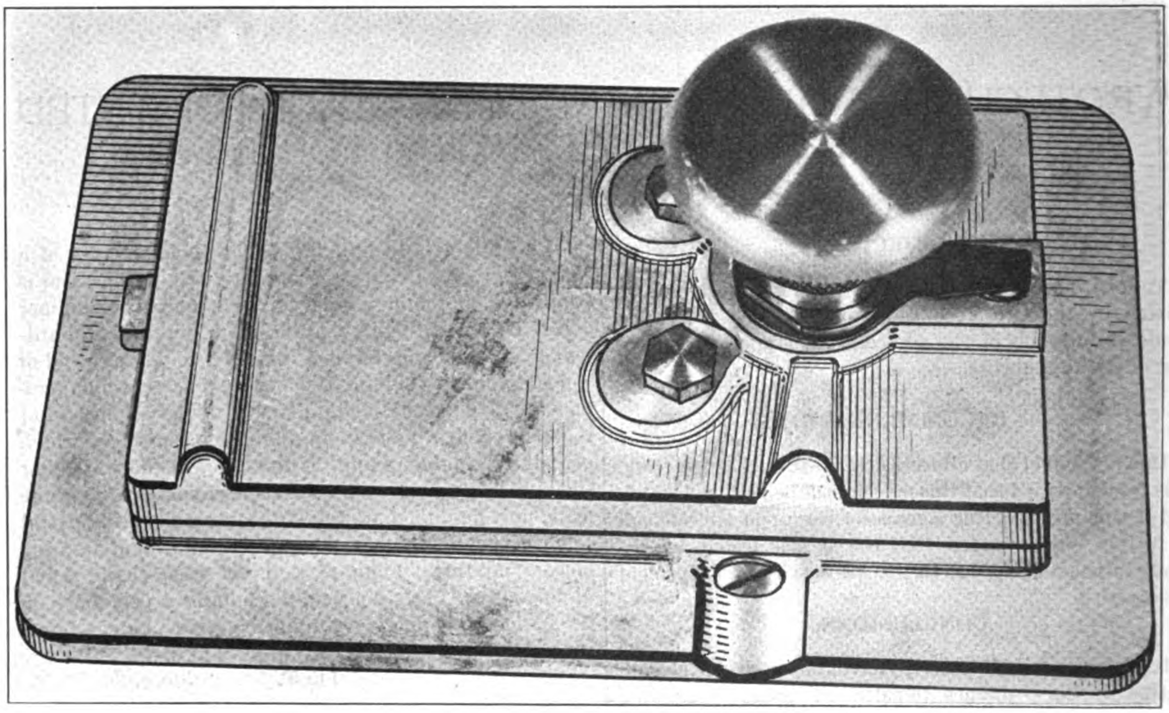


Fig. 1.—Pyrotechnic projector (top view).

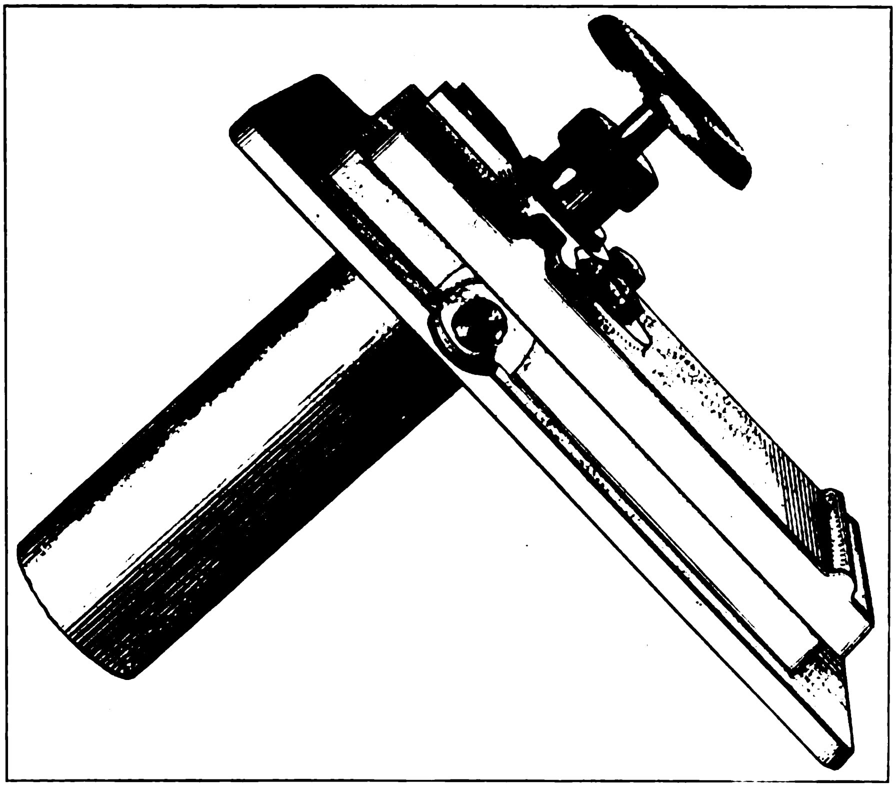


Fig. 2.—Pyrotechnic projector (side view loaded).

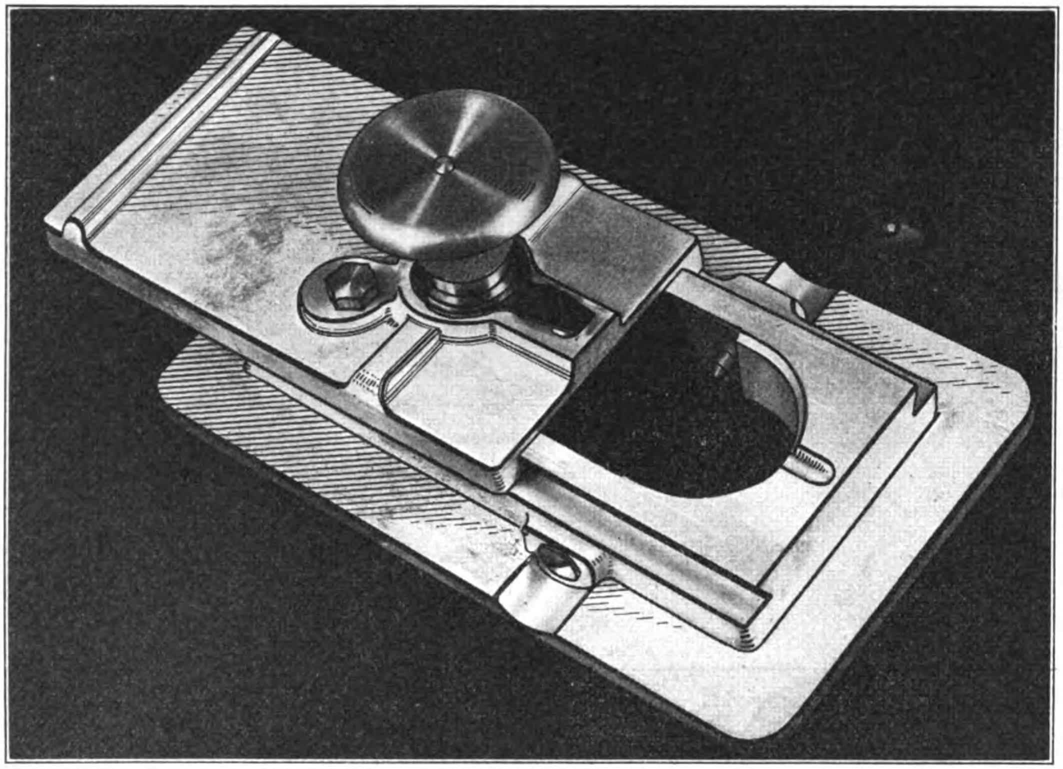


FIG. 3.—Pyrotechnic projector (quarter view).

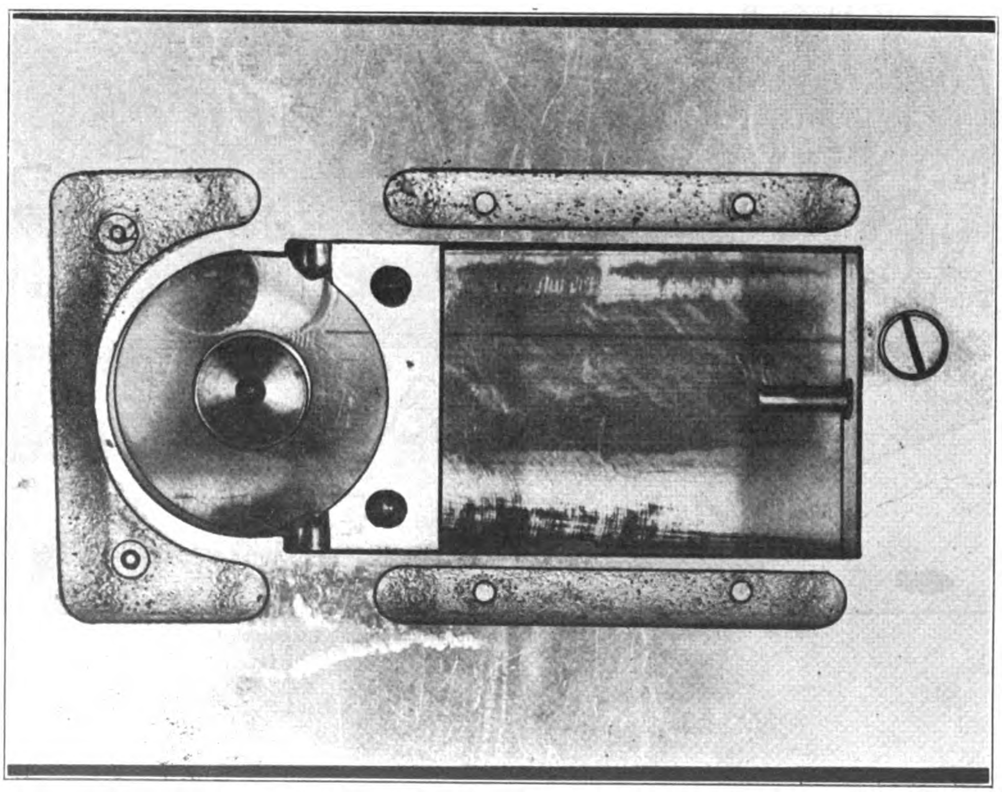


FIG. 4.—Pyrotechnic projector (bottom view).

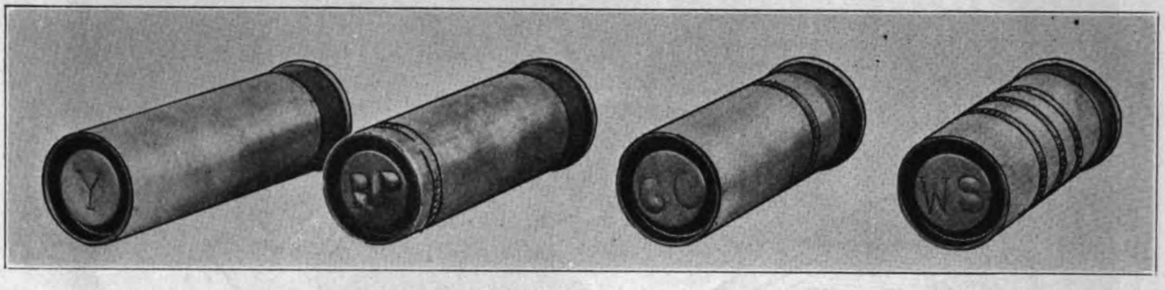


FIG. 5.—Pyrotechnic projector ammunition.

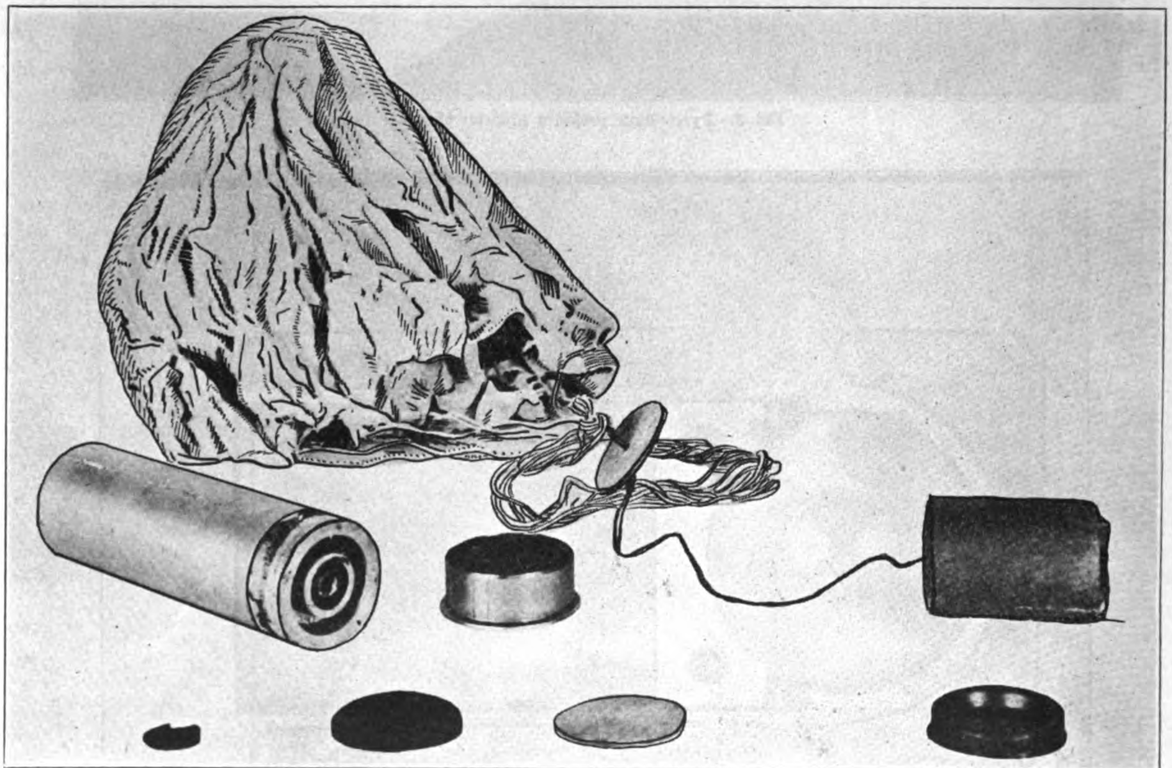


FIG. 6.—Pyrotechnic projector ammunition (yellow smoke) disassembled.

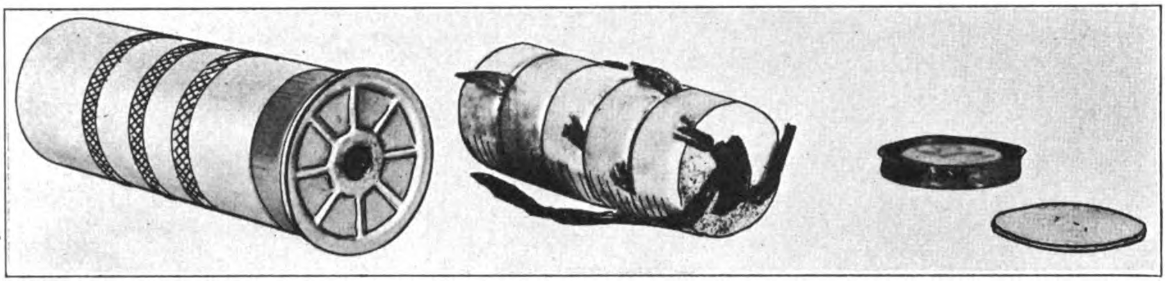


FIG. 7.—Pyrotechnic projector ammunition (white star) disassembled.

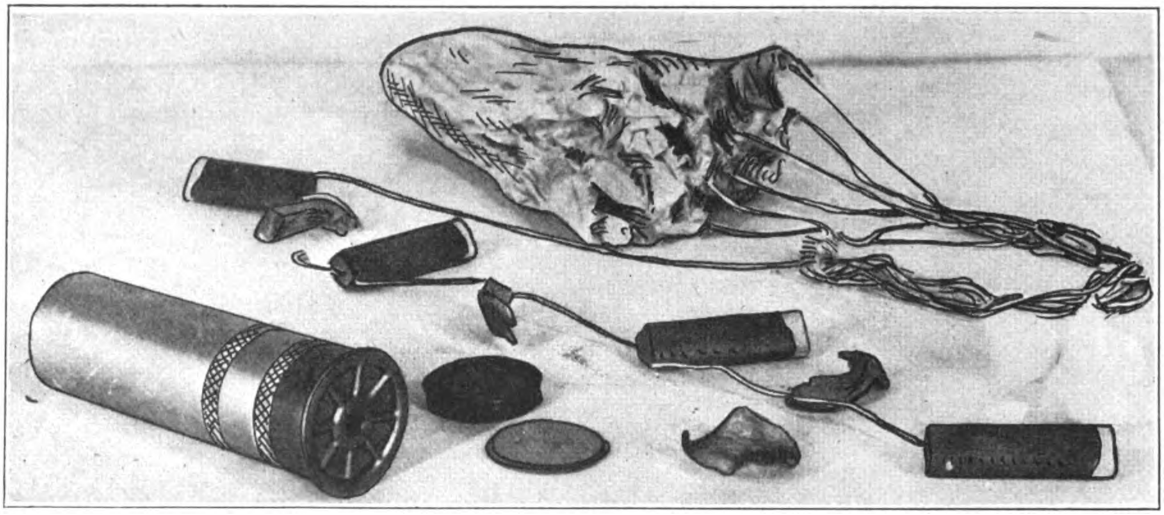


FIG. 8.—Pyrotechnic projector ammunition (green chain) disassembled.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | November 1, 1922 | No. 390

SEDIMENT DEPOSIT IN CARBURETORS

(MATERIAL SECTION REPORT No. 183)

▽

Prepared by A. C. Zimmerman
Engineering Division, Air Service
McCook Field, Dayton, Ohio
July 31, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

SEDIMENT DEPOSIT IN CARBURETORS.

GENERAL.

The difficulties encountered with the jelly-like precipitate found in carburetors are not new ones, as can be shown by previous correspondence and reports. A letter on the subject of carburetor sedimentation and the means of preventing same, dated November 16, 1918, was translated from the French, the introduction reading as follows:

"A considerable amount of trouble was experienced by the engine division with American Zenith carburetors, by reason of a deposit which was apparently caused by corrosion of the aluminum. In several cases it was said to have been the cause of crashes, and we were requested to recommend a remedy for this trouble."

A memorandum was received in regard to this same white deposit found in carburetors, requesting that a more sensitive test be devised for determining the acidity of fuels. This was written on the strength of assertions of previous investigators that the deposit was due to either sulphuric or sulphonic acids, either not removed or else formed in the refining.

Samples of this corrosion have been submitted from various aviation fields at different times. Not only that found in carburetors but also in the aluminum gasoline tanks. One carburetor brought to our attention contained considerable jellylike masses, sufficient to prevent its functioning.

PURPOSE.

To determine the chemical content of a sediment often encountered in carburetors, to determine the cause of its formation, and to find a means of overcoming the difficulty.

CONCLUSIONS.

The bulk of all the deposits analyzed consisted of the oxide of aluminum in the various stages of hydration, from aluminum hydroxide to practically anhydrous oxide of aluminum. Most of the samples of corrosion were contaminated with organic matter, a small amount of sulphates, chlorides, carbonates, and the oxides of iron.

The aviation gasoline in use at the Engineering Division, Air Service, McCook Field, will not in itself cause the corrosion of aluminum alloys used in carburetor manufacture. The cause of this corrosion is attributed to the presence of water, which probably condenses in small droplets and, due to its higher gravity, finds its way to the bottom of the containers below the gasoline level. The gasoline above prevents the evaporation, so that there is a gradual accumulation. Twenty-four hours' contact of this water with the aluminum alloy castings employed caused considerable corrosion. In one week's time a large amount deposited.

Of the corrosion preventive applications investigated, the special gasoline-proof baking black enamels gave very satisfactory results. The coatings should be applied by means of an air brush, as this method of application fills the surface pores more satisfactorily. This enamel must pass the following test:

GASOLINE-WATER TEST.

One coat shall be applied by means of an air brush to a cast cup 2¼ inches inside diameter, 3 inches deep, of ¼ inch wall thickness, made of aluminum alloy, the same as used in carburetor manufacture. Place 100 c. c. of gasoline and 25 c. c. distilled water in the cup and allow it to stand for 100 days. At the end of this period there should be no visible sediment, precipitate, or signs of corrosion in the cup. The solution shall be clear and the coating unaffected.

MATERIAL.

For exposing the various coatings to the action of gasoline and water, the standard porosity cups, 2¼ inches inside diameter, 3 inches deep, and ¼ inch wall thickness, were used. The 10 per cent copper, 90 per cent aluminum alloy, which is used in the manufacture of carburetor bowls was used "as cast" in the tests. The water glass used was the ordinary commercial variety, diluted in accordance with Specification No. 20002. Several air-drying black enamels, spar varnish, special gasoline-proof dope, shellacs, and baking enamels were investigated as to their exposure properties against gasoline and water.

METHOD OF PROCEDURE.

Quantitative chemical analysis was performed on all samples of carburetor and aluminum gasoline-tank sediments submitted by various aviation fields and by the different sections of the Engineering Division. These analyses consist in the determination of the loss in weight of the deposit upon heating to 100° C. and also upon ignition. The metallic elements and acid radicals were next determined.

Porosity cups of 10 per cent copper and 90 per cent aluminum were made in the foundry for the purpose of testing different corrosion inhibitors. Two cups were given identical treatments for every application under investigation. One set of cups was tested untreated for comparison with the coated cups, and to compare the nature of the deposit formed with that acquired in service. One of the two cups of each set was tested against gasoline alone, while the other was tested with both water and gasoline. The following list gives in detail the coating and the method of application and exposure:

Nos. 1 and 2. No coating. Exposed April 10, 1922.

Nos. 3 and 4. Treated with water glass according to specification. Exposed April 10, 1922.

Nos. 5 and 6. Treated with water glass, baked three-quarters of an hour at 350° F., washed with hot water, and dried. Exposed April 10, 1922.

Nos. 7 and 8. Same as Nos. 3 and 4, except that they were washed out with hot water after drying in the air. Exposed April 10, 1922.

Nos. 9 and 10. Sample No. 715, air-drying black enamel from Lowe Bros. Applied with air gun. Exposed April 10, 1922.

Nos. 11 and 12. Sample No. 387, baked, black enamel, Lowe Bros., for three hours at 350° F., thinned with 10 per cent turpentine and applied with air gun. Exposed April 10, 1922.

Nos. 13 and 14. Sample No. 1210, baked, black enamel, Kay & Ess Co., for three hours at 350 ° F., thinned with 10 per cent turpentine and applied with air gun. Exposed April 10, 1922.

Nos. 15 and 16. Sample No. V–306, Valspar, Valentine Co., thinned with 50 per cent turpentine, air drying, dipped. Exposed April 10, 1922.

Nos. 17 and 18. Sample No. 83383, red Engenamel, Du Pont, thinned with 50 per cent Du Pont thinner, air drying, dipped. Exposed May 4, 1922.

Nos. 19 and 20. Sample MS/672, bright black enamel, Du Pont dope, thinned with Du Pont thinner 50 per cent, No. 85882, dipped. Exposed May 12, 1922.

Nos. 21 and 22. Sample No. 1072, Noco, Non-Corrosive Paint Co., not thinned, dipped. Exposed May 13, 1922.

Nos. 23 and 24. Wade lacquer, not thinned, dipped. Exposed May 19, 1922.

Note: 25 c. c. distilled water added to all even numbers.

RESULTS.

The deposits submitted ranged from jellylike masses to hard crystalline granules, the analysis of which showed them to be of approximately the same constitution, excepting as to the water content. Each of the samples upon exposure to atmosphere lost a part of the water content and eventually took on the crystalline form. Analysis of the jellylike substance showed it to be principally aluminum hydroxide, which upon exposure to atmosphere became dehydrated to the form of oxide of aluminum.

A sample of dried sediment taken from an aluminum gasoline tank showed the following approximate analysis:

	Per cent.
Hydrated alum oxide	82
Aluminum sulphate	3½
Chlorides	5
Carbonates	5
Iron	2
Organic matter	2½

Another dried sample submitted by Lieutenant Ward from another flying field, taken from the bowl of a carburetor, showed a very similar analysis. A carburetor brought to our attention contained considerable jellylike masses, sufficient to prevent the functioning of the carburetor. An analysis of this material while still in the moist condition give the following results:

	Per cent.
Water	78
Alumina	15½
Organic matter	5½
Iron, sulphates, chlorides, etc	1

In the above analysis it is seen that 78 per cent of the formation found is water. In fact, water was found in all sediment submitted. The tests of the jelly proved conclusively that the compound was aluminum hydroxide. Distilled water in contact with this alloy of aluminum gave a deposit which showed a similar analysis and which visually had the same constitution, with the exception that the organic matter was absent.

Table 1 constitutes the outline of the results obtained when the various applications were exposed to the action of gasoline alone and to gasoline and water.

DISCUSSION OF RESULTS.

The conclusions drawn as to the nature of the deposit found in carburetors are substantiated by analysis on five samples of deposit sent in for examination from various localities, which no doubt use fuel from different sources. Although the analysis of the samples showed the presence of sulphates, chlorides, iron, copper, etc., these impurities formed only a very small proportion of the whole, so that the chief concern lay in the hydroxide of aluminum. Previously, without thorough investigation, the deposit has been reported as principally sulphates, carbonates, etc., but upon closer study no doubt exists as to the real composition of the precipitate. Its appearance alone, while in the moist condition, eliminates the conclusion that it is composed of sulphates, chlorides, or carbonates of aluminum.

When the alloy is immersed in gasoline alone, no sign of corrosion is evidenced. If a little distilled water is added, however, a similar flocculent precipitate forms in a very short time. Even in the absence of gasoline, a deposit of the same composition as that found in carburetor bowls forms. It is thought that the action of carbon dioxide dissolved in the distilled water is responsible for the attack on the aluminum. The assumption is that the weak carbonic acid dissolves the aluminum, with the formation of aluminum carbonate, which, because of its unstability, breaks down to aluminum hydroxide and carbon dioxide according to the following equations:

$$2Al+3H_2O+3CO_2=Al_2(CO_3)_3+6H.$$
$$Al_2(CO_3)_3+3H_2O=2Al(OH)_3+3CO_2.$$

It will be seen that the carbon dioxide which furnishes the reaction in the first equation is again liberated in the second, so that it is not consumed but is present for further attack on the aluminum. The fact that a precipitate is formed and that the cause of corrosion is regenerated, there should be no stop in the formation of the precipitate. Exposure tests bore this out.

Referring to the report of the determination of water in gasoline, it is evident that water must get into the tank and settle to the bottom, since not enough water can

originally be dissolved to cause this amount of corrosion. It is thought that the air in the tank at the low temperature of the higher altitudes reaches the dew point, which causes the accumulation on the tank sides and eventually runs to the bottom. After it once gets to the bottom with the blanket of gasoline covering it, it can not evaporate again. In time, therefore, considerable could collect and reach the bowl of the carburetor.

In the table of results obtained on exposure by the use of various treatments and applications, it will be seen that all failed, except those which were baked. The baked water-glass treatment and the two black baking enamels gave satisfactory results when exposed for 100 days to water and gasoline. The remainder of the treatments either would not resist the action of gasoline or water, or both. Some became gummy in contact with gasoline, others too brittle to withstand vibrations, and a few changed color below the water level, which showed that they had deteriorated.

On the strength of the results of this investigation, it is recommended that a specification baking enamel be applied by means of an air brush to all aluminum bowl carburetors. The specification for this enamel is being formulated at the present time.

TABLE No. 1.

Cup No.	Exposed to—	Treatment.	Exposure.		
			7 days.	80 days.	100 days.[1]
1	Gasoline	None	O. K.	O. K.	O. K.
2	Gasoline and water	None	Slight jelly-like precipitate	Large amount precipitate	Failed.
3	Gasoline	Water glass, air-dried	O. K.	O. K.	O. K.
4	Gasoline and water	do	O. K.	Solution hazy	Failed.
5	Gasoline	Water glass, baked, and washed	O. K.	O. K.	O. K.
6	Gasoline and water	do	O. K.	O. K.	O. K.
7	Gasoline	Water glass, air-dried, washed	O. K.	O. K.	O. K.
8	Gasoline and water	do	O. K.	Large amount precipitate	Failed.
9	Gasoline	Black enamel, air-dried	O. K.	Coating gummy	Failed.
10	Gasoline and water	do	O. K.	do	Failed.
11	Gasoline	Black enamel, baked	O. K.	O. K.	O. K.
12	Gasoline and water	do	O. K.	O. K.	O. K.
13	Gasoline	do	O. K.	O. K.	O. K.
14	Gasoline and water	do	O. K.	O. K.	O. K.
15	Gasoline	Spar varnish	O. K.	O. K.	O. K.
16	Gasoline and water	do	O. K.	Solution hazy	Failed.
17	Gasoline	Dope	O. K.	O. K.	Failed.
18	Gasoline and water	do	O. K.	Solution hazy	Failed.
19	Gasoline	Special gasoline-proof dope	O. K.	O. K.	O. K.
20	Gasoline and water	do	O. K.	Coating attacked by water	Failed.
21	Gasoline	Shellac	O. K.	O. K.	O. K.
22	Gasoline and water	do	O. K.	Coating attacked by water	Failed.
23	Gasoline	do	O. K.	Coating brittle	Failed.
24	Gasoline and water	do	O. K.	Coating attacked by water	Failed.

[1] "Failed" in this column means either that a precipitate formed, that the solution became hazy, or that the water caused a color change in the coating, or that the coating became gummy or brittle.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV November 1, 1922 No. 391

REPORT OF INSPECTION TRIP TO FRANCE, ITALY, GERMANY, HOLLAND, AND ENGLAND, MADE DURING THE WINTER OF 1921-1922

TECHNICAL SUPPLEMENT

▽

By

Brigadier General William Mitchell, 1st Lieutenant Clayton Bissell
and Aeronautical Engineer Alfred Verville

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

TABLE OF CONTENTS.

FRANCE.

ITALY.

GERMANY.

HOLLAND.

ENGLAND.

GENERAL.

FRANCE.

RÉSUMÉ OF FRENCH RESEARCH, DEVELOPMENT, AND SERVICE AIRCRAFT.

French experimentation is concentrated on development of all-metal types and, unquestionably, metal construction is the keynote of French development to-day. The requirement that all their airplanes shall be capable of being stored indefinitely under any weather conditions without major harm has had much to do with the dominance of metal construction.

The principal research work that is being conducted by the aerodynamic section is in the development of efficient internally braced airfoils, investigations in stability and in the controllability of aircraft, more accurate determination of scientific data for mathematical design of propellers, investigation of the most efficient control surfaces, the problem of developing suitable methods of effecting mechanical control for large multimotored airplanes as an aid to the pilot, investigations as to the influence of interference in all types of aircraft, the accurate determination of correction factor data for application from wind tunnel models to full-scale work, and the exploration into the question of the influence of very high velocities in correct mathematical interpretation on general airplane properties.

The future French training types will be studies in all-metal construction. The Gourdou monoplane is a very representative type of French single-seater pursuit, although it is underpowered to meet the new pursuit requirement. The fuselage, landing gear, and tail surfaces are duralumin tubing with steel fittings, very similar to the Breguet type. Biplace pursuit and reconnaissance types can be realized with the 500-horsepower engine, but inasmuch as this necessitates a very heavy machine, the French have so far confined themselves to lower-powered motors equipped with superchargers to obtain high performance at altitudes with less structural weight.

Detachable tanks are considered very much better than the rubber-coated tanks where it is possible to use them. Most of the French types have been designed and laid out for long-distance work of an offensive nature. They require a large amount of gas in order to fulfill their missions. The French have stipulated that the excess gas to be carried for the cross-country passage to combat points may be placed in removable tanks to an average extent of about one-fourth of the total amount of fuel required. The position installation of these removable tanks, however, has not been stipulated. It is understood that they are to be placed on the outside of the machine so as to reduce the cubical capacity of the fuselage. This will be an advantage in procuring more efficient aerodynamic outline and partially removes the restraint and embarrassment as to disposition of equipment, accessories, and fuel within the airplane proper.

It is significant to note that one of their most important requirements for their two-place, armored machines is that they be capable of making a figure "eight" between two points situated 100 meters apart. The fact that this must be done at an altitude of 100 meters is a criterion of the ability of this machine to maneuver for position. The French require that pilots' seats shall, in all types, be capable of being regulated in height, and armored seats are provided wherever possible. Silencer apparatus is to be applied on all their night bombardment ships.

Twin-motored types of bombardment ships have been absolutely discounted by the French air service. They have stipulated that all their future multimotored machines shall be of three or four motors and capable of flying on one-half or, at most, two-thirds of their horsepower. Self-starters are to be provided on all their night ships and the propeller flanges equipped with adapting clutches for field starting. All their new machines are designed with provision for self-starters from the cockpit. Their representative field starter in service to-day is the Odier type. We have a sample of this starter at McCook Field.

The colonial type airplane (specifications attached) is to be of such design that it can be easily transformed to a bombardment ship. It will be multimotored and will carry a minimum of eight persons. Specifications governing this type are very interesting. They evidence the attention that is being given to the development of this special type for distant work in the colonies and for use under adverse climatic conditions. They are able to operate at great distances with heavy bomb load.

On all pursuit planes having fixed gun installations the cowling immediately around the gun mounting must be easily removable and provided with fasteners which can be adjusted quickly. Under no conditions will they permit the cowling to be bolted down. The modern tendency governing bomb installations is favoring the internal bomb rack for most of their machines where the size of bombs does not place a limitation on the initial structural layout. For their larger bombs they still use external supports.

Communication between pilot and observer must be by voice without the use of an aviophone. Where this is absolutely impossible, a passageway facilitating direct communication between pilot and observer is required. Crews are no longer permitted to be placed as in the Salmson types. Parachutes must be provided for all the personnel in all their types.

Another important requirement is that power plants must be completely changed in eight hours with two mechanics. Their gasoline pumps must be designed to feed any one or two of their motors. Starting of the

motor by hand or whirling of the propeller is to be absolutely discounted on all types. The specifications as to fuel supply requirements for all their different types are interpreted in terms of sea-level consumption so as to facilitate an accurate understanding with designers as to actual amount of gas required on all their types. The development of propellers to resist all extremes of climatic conditions is being pushed and will be provided on all their types as soon as possible.

Experimentation relative to the development of suitable duralumin floats is being conducted with their seaplane work. Deck landing trials are being made regularly with the idea of developing means to retard the progress of the airplane on landing and to provide the best methods to prevent the plane from going over the side of the ship. Their idea as applied to their ship planes to date has been the use of a hook attachment, about 10 feet long, fastened to the underside of the fuselage, immediately back of the landing gear. It can be dropped by the pilot and its rear extremity engages the ropes that are set transversely across the deck. These are fastened to sandbags. This method does not produce a very marked shock to the machines, owing to the leniency of resistance produced by moving the sandbags. Shock-absorbing devices in the forward extremity of the long metal hook are fastened to the underside of the airplane fuselage.

The French have been attaching considerable importance to the development of very high speed racing aircraft such as has been evidenced in the Nieuport Delage Sesquiplan. One of the main objects is to ascertain from trials in full scale the relation between the performances realized and theoretical performance advance rom laboratory experiments. It is their desire to determine standard correction factors that will be applicable in full-scale tests and to determine the value of different air foils and resistance factors at high velocities.

Preparing for and conducting racing meets is very expensive, but the benefits to be derived for general technical aeronautical purposes are of great value and open up technical research and center attention in a new domain in which everybody is more or less concerned. The development of pursuit is in a large measure dependent on the development of speed machines.

A brief reference to the work of the leading companies in France will give an indication as to the trend of opinion and development in French aeronautical circles. These references are necessarily brief in a résumé ot this kind. but complete details covering the ships referred to will be found in another part of this report.

The Spad Co. is still developing monocoque construction and attribute their faith in it to the superior aerodynamic outlines that can be obtained. They have procured superior performance both in endurance and speed for a given period. Their new single-seater, high-altitude, pursuit type, and their new two-seater, high-altitude, pursuit and observation type in monocoque will be completed soon and should be followed closely. The performance and ultimate function of these two machines represent the overcoming of inertia of development on these two particular types. They have been found desirable by the French for pursuit and are being built to type specifications in experimental fashion. Full description of these machines will be found under the proper heading.

The Spad "Side-by-Side" training type is another radical departure for instruction purposes. The trend of opinion in American and European aeronautical training circles should be derived and conclusions drawn from it as to the desirability of this type for our ultimate training program. It is probable that a conclusive opinion may be reached in short order by our experience with the new two-seater Dayton-Wright training type which has just been completed and submitted for test.

The Nieuport Co. is still sticking to monocoque construction, and inasmuch as they have been endeavoring to attain the utmost in streamlining, they consider that this type construction is best adapted to attain the higher degree of fineness that is necessary. The performance obtained during the last four years with the Nieuport 29 has been sufficient evidence of the correctness of their theory. This machine is probably the best and most highly developed pursuit ship in the world.

The Breguet Co.'s interpretation of all-metal construction in their single-motored types is practically the same as they have used for the last four years and has been giving entire satisfaction. It is truly representative of French all-metal standard type construction and satisfactorily stood the test of service conditions in the World War. It is still being developed and used by the French air service. The type of construction used in the Breguet Leviathan represents a departure from the orthodox method, but is too complicated to be practical.

The Potez Co. has been working on a different adaptation of metal construction in their later models. They are principally prototypes of some of their earlier machines. Their master construction ideas are principally toward the use of duralumin shapes, such as channels and angles with gusset-joint construction as their characteristic interpretation. Very satisfactory physical evidence of this type of construction has already been produced, and tests being conducted will tell how well adapted this type of construction is under field conditions for production, accessibility, and maintenance. Their motor mountings are complicated, although they are very robust. They build the engine in, frame fashion, and employ a great number of rivets.

One of their latest models is a three-motored bombardment or passenger-carrying plane, which is their best interpretation of the French three-motored, long-distance, night bombardment specifications. It is designed, as hereafter mentioned, under the specifications requiring a central fuselage with twin wing motor installation. I believe that tubing is far more economical from a structural standpoint than this type of construction.

The Wibault Co. has developed a radical interpretation of a single-motored, night bombardment ship absolutely different from any of the existing French prototypes. This machine has been conceived with the fundamental idea of preserving the most efficient aerodynamic outline possible. The machine is all-metal construction and has the entire load of accessories, bombs, and fuel disposed within the structure proper. This machine has recently made its first test flights and should be observed closely with a view to ascertaining the advantage of this type for the fulfillment of its night bombardment mission.

The metal construction has been very thoughtfully carried out and, although it does not represent the utmost in simplicity to be desired, it is the most representative type of up-to-date all-duralumin construction in a French military machine. This machine has been very thoughtfully designed to meet the specifications that have been laid down by the French air service. The absence in the major part of their metal construction of a lot of flimsy sheet duralumin pieces, and the utilization of tubular construction wherever it has been possible, are the outstanding features of the Wibault machines. This machine should be very closely studied to determine whether or not it would be desirable for us to do experimental work along the same general lines.

The Wibault Co. is also constructing a single-seater, supercharged pursuit plane of the "parasol monoplane" type, motored with the Hispano-Suiza, which should be very closely observed in its development. If it has the desired maneuverability, it will represent a type suitable for pursuit work at altitudes.

Mr. Wibault employs fabric for all his surface and fuselage covering. The advantage is the ease of inspection of the internal-construction units, accessibility, and ease of replacement. Deterioration in the field when exposed to the weather is going to make the covering relatively short lived, but this deterioration requires only the replacement of fabric and not of any major structural part. This is a point to be very seriously considered in our own program when studying the design and construction of our future all-metal wings. In considering whether or not we will adopt metal wings with fabric covering or metal wings with metallic covering, it should be remembered that the advantages or disadvantages in either case are not alone concerned with the covering.

The Morane Saulnier Co. has designed and built during the past year an internally braced monoplane with tapered wings, powered with three 370-horsepower Loraine engines or three 400-horsepower Liberty engines. One of the engines is located in the nose of the fuselage and the other two engines are located immediately to either side and in the leading edge of the monoplane wing. The structure of the machine is entirely of metal elements, although the wings and fuselage are covered with fabric. The wing spars are duralumin trellis-type girders. The landing gear is of the two-wheel type with two vees extending from the bottom of the fuselage out to the wheels and with the compression truss extending up from the wheel shock-absorber point to the underside of the wing engine mounts. The wing is divided practically into three distinct plan sections, the center section being of a uniform chord and depth, while the outer sections from the engine location taper toward the wing tips, both in chord and depth. The control surfaces are all balanced. The engines are so disposed as to prevent the blanketing of the respective propeller-disk areas. The fuel tanks are situated in the wing just over the outboard engines and no fuel is carried in the fuselage. Fuel capacity is sufficient for seven hours' flight with full load. Provision is made, however, for the immediate emptying of the fuel tanks, should the necessity arise in flight.

The fuselage is of rectangular section and has nose radiator mounted for the fuselage engine. Control compartment is fitted with two seats ahead of the wing, affording excellent visibility.

A tunnel leading from the control cockpit to both wing engines enables the mechanic to make motor adjustments in flight, and the central engine, of course, may be directly reached from the control cockpit proper.

This machine has recently been completed and is now ready to undergo tests. It has been designed, however, as a passenger carrier and provisions are made for the location of 16 passengers. However, this machine is readily adapted for conversion into a bombardment type, and if the experiments prove out well on this first machine it will be converted into a military type. It represents a very novel type and has really been influenced in design by the advent of the large Zeppelin Staaken type. Being a three-motored job, it will blend in well with the requirements of the French bombardment type specification requiring three motors. Flight tests will be conducted very soon at Villacoublay, and the results should be watched very closely.

FRENCH PROGRAM FOR NEW AIRPLANES.

EXPLANATORY NOTE.

The French have laid down a definite program for their new airplanes which contains a discussion of requirements with suggestions for their installation. This program for new airplanes has been translated from the French using as free a translation as possible in order to make the information understandable even to a layman. In several instances, however, it was impossible to give a free translation and maintain the exact meaning of the French. In other cases there was some question as to exactly what was meant and in both of these instances a literal translation has been given.

Table of French aircraft.

Type.	Existing or experimental.	On order.
Pursuit, low altitude	Nieuport 29 C-1. Hanriot. Spad.	Nieuport. Spad.
Pursuit, high altitude, supercharged	Nieuport.	Spad. Wibault. Nieuport.
Pursuit and reconnaissance, 2-place, observation.	Breguet. Spad. Farman. Hanriot. Salmson. Potez.	Hanriot. Gourdou. Spad.
Day bombardment	Breguet. Farman.	Potez.
Night bombardment	Breguet. Farman.	Morane. Wibault. Potez. Latecuere
Ship planes	Nieuport. Hanriot.	Spad.
Torpedo planes		Farman.
Training	Hanriot. Morane. Caudron.	Spad.

I. GENERAL QUALITIES REQUIRED.

Power.—The basic French plan to improve the flying performance of their aircraft is to make the most efficient use of power rather than in increasing it.

Of two airplanes which bear the same load with the same speed at the same altitude, the one using least horsepower is much the better, since it permits of greater maneuverability, is easier to land, and has a smaller consumption of heavy, costly fuel.

Number and types of motors to use.—Light, fast, maneuverable airplanes would necessarily have a single motor.

Efficiency.—Special attention of the constructors is called to the increase in the efficiency of airplanes which can be obtained by careful study of the lifting quality of the wings, of the parasite resistance of the accessory parts, and of the efficiency of the propeller.

The lifting quality depends upon the choice of the profile and upon the resistance of the wings.

Actual experience has shown that from a lift viewpoint the best biplane wings are those which have the lower plane narrower and which have forward stagger.

Head resistance of the airplane should be studied for each part, and the shape of the fuselage will be such that it will hold all the accessories.

The question of water and oil radiators will be particularly investigated, as will also the air outlets of the fuselage, which actually occasion very great resistance by the whirls which they cause.

In general, the head resistance of an airplane of a series of separate parts is greater than the sum of the resistances of the parts considered alone, and much greater than the resistance of the parts grouped in a single body even though the individual resistance is large.

The efficiency of the propeller will be augmented by the choice of its profile. The narrow propeller of great diameter has been shown to be the best simultaneously by the experiments of the laboratory and direct measures of the performances on the airplanes.

In all cases, when possible, the propeller should turn at a low number of revolutions. Gear reduction is interesting if it functions well, even for fast airplanes.

With the present motors, a reduction of one-half could be considered as desirable on all airplanes.

Such a reduction augments by 9 per cent the efficiency of the propeller if it is alone on its shaft: $P_1 = P_0 \times 1.09$; and by 12 per cent if it is tandem with another propeller: $P_1 = 1.12\ P_0$.

This augmentation of efficiency also holds true for the greatest speeds actually practiced.

High-altitude airplane.—For high altitudes the determining element is the weight of the motopropeller group brought from the useful power to the maximum height attained by the airplane.

High-altitude airplanes present two totally different problems.

The first solution involves the use of very light motors, air-cooled if possible, calculated for functioning in cold air at high altitudes and provides with a checked feed for low altitudes, so that the pressure and the temperature borne by the parts might not be excessive.

The second problem permits the use of motors calculated for functioning at sea level. This is accomplished by feeding gas to the carburetor at a pressure practically constant This solution involves a turbocompressor.

Airplanes for medium altitudes.—The airplane for medium altitude must be easy to fly and must have a motor without complicated accessories. One designed for regular functioning of many hundred hours will be the best.

Heavy airplanes.—Heavy airplanes will certainly have to be either three or four motored to be dependable. These motors will be chosen primarily from the standpoint of reliability. Their installation and accessories shall be completely independent so that the failure of one motor or any of its accessories will not produce the failure of several motors such as might be the case if they had accessories in common.

The bimotored plane is the most dangerous to handle in case of failure of one motor, is the least regular in operation, and should not be further considered.

Stability.—Airplanes ought to be inherently stable, climbing gradually if the motor is accelerated or gilding normally if it is throttled.

When the motors are cut out the airplane should automatically start to glide at an angle which is slightly greater than the normal gliding angle of the machine.

In a turn, with motor full speed or cut out, under the action alone of the rudder, the airplane should tilt naturally to make the drift negligible.

Compensation of multimotored planes.—In the multimotored airplanes a contrivance will be provided to permit counteracting the unbalancing effect from the stopping or the loss of power of any of the motors without subjecting the pilot to additional fatigue. An example of this is a compensator on the rudder bar to prevent the plane turning to the right or left.

Longitudinal equilibrium.—An airplane with a full load should be balanced longitudinally for ordinary flight conditions with the motor turning at its normal revolutions. Of course this means at the altitude for which it was designed. It must not be tail heavy or nose heavy.

Maneuverability.—Response to controls should be very easy so that the airplane will not be fatiguing to the pilot. The effort required by the pilot should always be proportionate to the effect desired.

This result is easily obtained by using as ailerons, elevators, or rudders, mobile surfaces relatively long and narrow, partially balanced and combined with carefully considered fixed surfaces placed before the movable surfaces.

In all cases the three controls should be designed to require a similar amount of muscular effort in the different evolutions of the airplane.

An airplane control which can easily be thrown out of gear should be provided for use of one of the observers in multiplace machines.

Comfort.—The crew should be arranged in such fashion as to avoid all unnecessary fatigue during a flight. Seats with upholstered backs should protect them from vibrations. They should be protected from the oil spray and the wind by windshields, or better yet, the profile of the plane should be such that the air flow does not strike them yet permits them to see without interposition of

glass or any other transparent substance. They should be protected from escaping gas.

Visibility.—The field of visibility of the pilot and observer will be one of the most important considerations in the design of any airplane. Details regarding visibility for different types of planes are given elsewhere.

Location of the observer.—In the multiplace machines, one of the observers, at least, should be placed very near the pilot, close enough to be able to communicate with him by voice without the aid of any acoustic apparatus. Each position should permit the use of a parachute. The pilot in any war machine must not be placed as in the Salmson.

Durability of airplanes.—All airplanes to be constructed should be capable of several hundred hours of efficient flying with absolute safety.

They should be capable of being stored indefinitely without deterioration.

They should be capable of being kept out in the weather without serious harm.

This demands that the wing construction, including ribs, be entirely of metal.

Paints, varnishes, or protective dopes should be used which would protect the thin sheet metal against climatic conditions.

Ease of assembly and maintenance.—Assembly should be simple and easy and covered by brief, clear directions. This requires that the parts be clearly marked and that the instructions cover the system of marking. The maintenance should be very easy and should not necessitate the employment of specialized personnel.

Interchangeability.—The manufacturers of airplanes should be directed toward the realization in the near future of perfect interchangeability of the parts. This is of great importance where the replacement of unserviceable parts must be made as rapidly as possible without skilled mechanics.

Equipment and armament.—All the airplanes should be submitted with their complete equipment and must make their trial flights carrying full equipment and armament prescribed for this type.

II. STRUCTURE STATIC RESISTANCE.

Wings.—As a general principle, the static tests under the control of the technical section should be made before the first machine leaves the factory.

For the load applied underneath the wings, the coefficients of safety to adopt should be the following:

$$\text{Pursuit and combat planes} \ldots\ldots 10 \frac{S}{To}\left(\frac{Vo}{100}\right)^3$$

$$\text{Other airplanes} \ldots\ldots\ldots\ldots\ldots\ldots 7.5 \frac{S}{To}\left(\frac{Vo}{100}\right)^3$$

In this formula S is the surface in square meters of the wings. To is the horsepower at sea level and Vo the speed in kilometers per hour at sea level.

These coefficients should be multiplied by 1.5 for mono planes.

If any one of the wires or any one of the attaching metal fittings of the wing should be taken away (or shot off), the wing should resist statically with a coefficient of one half less. This disposition is applicable to internal drift and wire fittings in the interior of the wings.

The wing should be submitted to dissymmetric static tests.

Fuselages and empennages.—The empennages should be built to support in the static tests a load of sand equal by m^2 to three-fifths of the maximum by m^2 supported by the wing in the static trial underneath.

The fuselages, loaded with weights double those which they must carry normally, ought besides to support the empennages loaded as stated above.

To verify their resistance to torsion, they should be submitted to dissymmetric test.

Landing gear, axle, and tail skid.—The stress which the landing gear, the axles, and the tail skids should bear before breaking should be at least equal to five times the static load with the airplane resting upon a horizontal surface.

These stresses must also have a horizontal component equal to half of the vertical component.

Elastic cords should be established so that the maximum strain may not be surpassed, the machine falling vertically from 0^m 50 if it is used on a day airplane; from 1^m if it is used on a night airplane; and the adjustment should be such that the elastic bands enter into play effectively, since the stress should not surpass that which they should bear at rest.

The tests should be furnished with a checking arrangement so that, in any case, the fixed parts of the airplane can not touch the ground.

The tail skid should be placed in such a manner that, after the maximum expansion of its elastic bands, the rudder and the stabilizer should not graze the earth in bad fields.

III. DETAILS OF CONSTRUCTION OF THE AIRPLANES.

Assembly.—Disassembly, reassembly, and transportation ought to be easy. The wings, particularly, should be able to be taken apart into pieces of not more than 8 meters in length, which can be easily transported by railroad.

Standardization.—For the parts for which the technical section will have specified standard tables, the dimensions figuring in the tables are exclusively specified. Standard tables are established particularly for the:

Steel.	Bolts.
Canvas and bands.	Turnbuckles.
Cables.	Tubes, round and stream line.
Piano wire.	Screw threads.
Tapering wire.	Cocks, valves, and brass work.
Thimbles.	Wheels.
Wire ferrules.	Propeller hubs.

Replacement.—It is necessary that all the parts which deteriorate ordinarily more often than the wings be easy to replace. These parts are the landing gear, tail skid, motors, radiator, tanks, etc.

It is indispensable that there be interchangeability of all assemblies or detachable parts capable of being replaced in organizations at the front. These different parts ought besides, to be marked in such fashion as to obviate errors in setting up (high, low, right, left, forward, rear, etc.).

Complete production drawings should be furnished to permit the rapid manufacture of spare parts, if necessary, and to insure absolute interchangeability.

Maintenance.—All the parts submitted to strain should be capable of inspection and easy replacement. It is

particularly so in the case of the crosspieces or the fuselage, of the tail-skid supports, of all control cables, guides, or pulleys over which they pass to the interior of the wings or from the fuselage, and of all the levers, aileron controls, etc., transmitting the movement from the control parts to the ailerons, elevators, and rudders.

Mud guard.—The wheels ought to be supplied with removable mud guards to obviate the throwing of mud or gravel into the propellers.

Steps.—Steps should permit the aviators to mount into the machine without risk of injury to the wing or any accessory. These steps should not permit the entry of air into the fuselage.

Seat.—The seat of the pilot should be adjustable in height.

Rudder bars.—The rudder bars are adjustable from one of the unified types adopted by the technical section.

Floor.—The floor should be furnished with an arrangement permitting the pilot to see the terrain under him; for example, controlled shutters and floor guard with openwork.

Controls.—All the control cables should be double, with separate points of attachment.

Wind shield.—All airplanes should be furnished with a windbreak or windshield for each person.

IV. SETTING UP OF THE MOTOR AND ITS ACCESSORIES.

A. General.

Management and function.—Every motor ought to be mounted so that its management may be easy.

It ought to be able to function without difficulty in any position of flight in which the airplane is likely to be placed. For pursuit airplanes, this means a zoom of 200 meters, dive of 1,000 meters, or glide under an angle of 30°. For multi-motored ships the feed ought to be assured for any turn effected with the minimum radius of gyration.

Every motor ought to pick up readily after a descent of 2,000 meters with the engine throttled.

Assembly and disassembly.—The motor should be constructed as directed by the State and no modifications destined to diminish the interchangeability on the airplane should be allowed without the consent of the technical section.

The replacement of a motor or of a group motor in an airplane, or of an important accessory, such as the radiator, tank, etc., must be able to be effected in less than eight hours, with two mechanics and with the ordinary facilities available in a light squadron workshop.

The disassembly of important parts, such as radiator, tank, carburetor, magneto, or pump, ought to be effected in less than three hours, without necessitating the complete removal of the motor.

Provisions should be made for the installation of such a type of connections and controls that the power plant may be removed from the airplane without difficulty in the minimum time.

Changing the motor ought not to necessitate the disassembly of any of the accessories—pumps, carburetors, or magnetos—which might be put out of order.

The cowling should be strong enough to withstand at least 10 disassemblies. Its replacement ought to be effected in one hour.

An opening should be provided for inspection large enough to permit access to the parts of the motor which need periodic surveillance: pumps, pressure gauge or regulator of the rate of flow, sights, filters, drain cocks, stopcocks, magnetos, distributors, contact breakers, carburetors, jet, constant level, and spark plugs.

The cowling, in spite of its removability, ought to be water-tight, and ought to potect the aviators, windshields, and sights from all oil or water spray.

Carburetors.—The carburetor mount should be designed to receive any of the different models of carburetors adapted to a same type of motor.

Precautions to obviate danger of fire are treated under the next main heading.

The carburetor and its frame should be heated and adjustment should be provided to permit an economical functioning for temperatures of 40° to 30° for all altitudes and at all speeds. The air admitted ought to be warmed.

Hours of flight.—The capacity of the tank or tanks for gas ought to correspond to the number of hours fixed for the running at sea level of the motors at full throttle. The capacity of the oil tank corresponds to the duration of the flight at full speed and at the specified altitude possible with this supply of gas, augmented by the minimum reserve for assuring circulation and a margin of safety of 20 per cent. The specific consumption of the motors increases with use.

The attached chart contains the basic elements of calculations for the tanks of gas and oil with the present motors and will be revised as new motors are designed.

Table of consumptions of oil and gas of aviation motors.

Motor.	Type.	Horse-power.	Maximum pewor T.	Power full limited admission at sea level T_1.	Specific consumption per horse-power hour in kilograms A.	Hourly consumption in kilograms ($T_1 \times A$).	Oil hourly consumption in kilograms.	Oil reserve in circulation.
STATIONARY MOTORS.								
Bugatti	16 C	450	460	420	0.250	105	8	4
De Dion-Bouton	16 A	800	900	800	.260	210	30	6
Hispano-Suiza	8 F	300	320	280	.245	70	6.5	4
Hispano Cannon	12 C	450	450	420	.250	105	8	4
Liberty	12 L	400	410	370	.240	92	6	4
Lorraine-Dietrich	8 B	275	275	240	.250	60	4	3
Do	12 Da	370	390	300	.250	75	8	4
Do	12 Ch	500	500	....	.250	125	10	....
Panhard-Levassor	12 O	340	340	320	.230	75	75	4
Do	12 E	500	520	480	.230	110	18	5
Do	12 Ez	500	550	480	.230	110	18	5
Do	16 F	600	690	640	.240	155	23	6
Renault	12 F	300	330	280	.250	70	6.5	4
Do	12 Kb	450	460	380	.260	95	11	5
Do	12 M	600	590	540	.260	140	15	5
Salmson	9 Z	230	260	230	.245	57	8	4
Do	18 Z	500	560	460	.235	110	20	6
ROTARY MOTORS.								
Clerget	9 B	130	135	125	.285	34	8.5	2
Do	11 Eb	200	200	180	.380	68	11	3
Rhone	9 Z	120	130	120	.285	33	6	2
Do	9 R	170	170	150	.280	42	7.5	2

Gas and gravity tanks.—The feed of each motor must constitute an independent assembly for gravity, pump, and service tank, and in addition any tank must be able to feed any motor.

Each tank should be able to be filled easily and quickly with an ordinary funnel and should be furnished with levels or gauges visible to the pilot. If the breakage of these levels risks involving the flow of the gas, a cock within easy reach of the pilot should permit cutting it out of the system.

Gravity tanks, with load of gas, should be provided at the rate of one for each motor. These gravity tanks are designed for continuing the flight for 50 kilometers in case of accidental emptying of the service tanks. They feed the motors directly and are protected.

Changing from service to gravity tank should be done automatically or at the will of the pilot.

Feed at full throttle should be assured automatically while there remains even 1½ gallons of fuel in any one of the principal tanks.

The leakage in a tank should not be able to involve the emptying of the other tanks.

Cocks optionally managed by the pilot should permit the isolating at will of any number of these tanks.

The pilot should be able to withdraw the gas in the full tanks at will, either by an automatic arrangement of pump or exhauster or by a hand pump made in such a fashion as to utilize all of the gas.

The use of tanks under pressure is forbidden.

The permanent refilling of the gravity tanks should be assured at will by the normal system of feed and by aiding with hand pumps. The flow, in the second case, should be sufficient to assure the normal functioning of the motors.

The automatic valves are completed by safety cocks. A cock, manageable by the pilot, should permit the cutting out of any one of the tanks, the carburetor, or the pump.

The supply tanks are furnished with an overflow pipe with circulation sight and of a diameter double that of the intake; the opening to the atmosphere should be made in a zone with a current of air.

Each pump should be able to feed any one of the motors and to have a maximum flow sufficient for the consumption of two motors.

The tanks are established in conformance to the specifications governing them.

Lubrication.—The lubrication of the motors should be done automatically, not demanding the attention or action of the pilot in the course of flight.

A control arrangement of the lubrication (manometer, sight, etc.) should be installed with a cock permitting isolation in case of breakage.

It would be advantageous to connect to the motor a system of direct injection of warm oil in the tubes which supply the bearings before starting the motor.

The valve limiting the oil pressure, and the oil filter should be accessible and easily disassembled.

The tube connections should be strong enough to permit effective clamping and provided with a control designed to prevent their coming open. Measures should be taken to prevent the deterioration of the hose connections by the extreme sharp edges of the metallic tubes. The ligatures should be made with rings.

The outlet tube of oil from the tanks should be surrounded with a strainer at least a centimeter high.

The oil should be maintained during flight at a temperature lower than 70° and higher than +10° for mineral oil and +5° for castor oil, whatever may be the outside temperature. This is to be done by means of radiators and nonconductors.

All the tanks should be surrounded by cork and the outside tubes should be insulated.

The blow valves of the motors and tanks should be arranged to obviate loss of oil by throwing oil vapors on the pilot.

All the tanks should be, as nearly as possible, in load on the pumps in order to utilize gravity to the maximum and to reduce the chances of unpriming the pumps.

Cooling.—The water-cooled motors should be furnished with a thermometer indicating the temperature of the water at the intake to the radiator (for airplane type a thermometer should be allowed for at the outlet of the radiator.)

The radiators should be placed as well as possible for protection from vibrations and should be supported completely, either by the motor or by the fuselage, and reinforced at the points of support. Water-tightness should be assured even if there should be a local tearing of the fixation rivets.

The different fittings should be reinforced by small rings. The water admission should be designed for using the flow with the minimum of resistance. The flow of the radiator in the weakest section and under a load of 0^{m} 40 of water should be at least equal to that of the water pump of the motor under the same governing load over the cylinder heads.

They should carry an emptying arrangement permitting complete evacuation of water, or refilling through the bottom. The stopper for this arrangement should be of standard dimensions. At the intake a fine filter should be installed to stop the impurities. This must be accessible. At their outlet a fixed filter with large mesh for stopping the grains of solder should be provided.

The radiators for any type should be established on a model in such a fashion as to be interchangeable in an airplane.

The highest point of the water circulation should be at least 0^{m} 60 above the most elevated point of the motor high point water system and should be furnished with an emptying stopper of a standard type. The high local points for the different positions of the airplane should be provided with tubes connecting them to the higher level. In any case, the water reserve should be placed above the higher level of the motor water system high point for a 20° angle of ascent or descent.

The cooling surfaces of the radiators should be calculated in such fashion as to assure a maximum difference of temperature of 65° between the surrounding atmosphere and that of the water at the outlet of the cylinders. at sea level, in the regions of France. This difference is to be reduced according to the latitudes for colonial airplanes.

A simple, strong apparatus should permit the regulation of the temperature of the water during flight. Its controls should be double and, in case of breakage, should automatically return to the position of the maximum cooling.

The radiators should be protected from earth thrown up by the propeller.

Cocks and levers.—All the cocks and levers which must be managed in flight should be in easy reach of the hand. Duplicated cocks and levers should permit the secondary pilot to manage the motor in case of necessity. Their dimensions and their position should permit of comfortable and effective management, even by hands covered with big gloves and in spite of a resistance of about 40 kilograms.

Control cocks with needle valves should be completed by cocks of one-quarter revolution, permitting rapid closing. They should be water-tight. Some safety devices should prevent the displacement of these cocks and levers under the influence of vibration.

The cocks and levers should all be furnished with legible indicating dials. The lever controls of the carburetor should bear a special notch necessitating a movement for being freed and provided with a stop corresponding to full limited throttle admissible at sea level. The altitude at which total admission is admissible should be printed upon the instrument board. The carburetor controls should, so far as is possible, be synchronized so their successive positions indicate the progressiveness of the number of revolutions of the motor.

Ignition.—The wires should be well insulated and terminated by unhookable clasps. No metallic parts should be found less than 1 centimeter from the ends of the longest spark plugs used.

A separate switch should permit the stopping of each motor, and a master switch should permit the stopping of the whole group of motors.

Manifolds.—The manifolds should be as short as possible, with streamlined shapes, constructed with the minimum number of elbows, and arranged with supports and flexible connections to obviate breakages under the influence of vibrations. They ought to be easily accessible throughout their whole length.

Account should be taken of the load and the resistances in the dimensions of the pipes, which should permit a load higher by 50 per cent at least than the necessary maximum under the most unfavorable circumstances.

Manifolds for gas, oil, and water should be immediately recognizable by their color. Special connections should facilitate this division from the motor to reduce to the minimum the number of flexible connections in sections.

Flexible connections should remain in good condition for at least two years.

Apparatus for the emptying of the tubing should be closed up, not by stoppers, but by special cocks.

Silencer.—The silencers must be easily removable. They should be as effective as possible, particularly for bombardment planes. The pilot and bomber should be able to hear each other. They should conceal the glow and be invisible at night. They should be able to resist vibration and expansion proceeding from heating. Their cleaning should be simple. The total absorbed power consumed by their weight, loss through checking of the gas, and the head resistance ought to be lower than 5 per cent of the total power of the motor in fast airplanes and 8 per cent in bombardment planes.

The exhaust gases should be discharged at a distance from the aviators, in order not to interfere with firing or observation, and must consider the direction of the suction of air by the propeller and of the slipstream eddies. This disposition at the side of the fuselage presents some advantages from this point of view.

Starting device.—All the motors should be supplied with a starting device on the dashboard, not requiring the whirling of the propeller by hand and assuring departure in less than five minutes regardless of temperature.

All the hubs, in addition, should be furnished with a propeller-hub clutch on the front of the propeller, permiting starting of the airplane motor with an airdrome mechanical starter.

Accessory controls.—Tachometer, manometer, and connections should be of standard type. Gasoline-pump controls should be standardized for each of the types. Flexible controls are allowed only on condition that they have no elbows.

Engine supports.—The motor bed and the wing fittings should be able to resist the maximum couple of the motor, with a coefficient of safety of at least 7, in order to take account of vibrations.

B. Measures of precaution to take against fire.

Causes of fire on an airplane proceed:

1. From the functioning of the motor and its accessories, and from accidents in landing.

2. From conditions of special present use in war (hits from projectiles, incendiary or otherwise).

3. From installation of special apparatus (compressed gas, different electric installations, etc.).

Only the two first groups will be considered in this note The appliances and special apparatus whose installation might be a cause of fire ought each to be studied from this point of view. It is impossible to establish precise rules of priority.

1. Causes of fire proceeding from the motor and its accessories.

The danger of fire proceeding from the motor can be caused by:

a. Gas from the exhaust.

b. Disposition of electric ignition.

c. Backfiring in the carburetor.

d. Excessive accidental leaks in certain parts of the motor.

In order that fire might spread it must meet a combustible substance—wood, canvas, oil, gasoline, or gasoline vapor.

For this reason no deposits of gas or oil should be allowed even momentarily. They should be disposed of immediately by effective ventilation. Possibility of leakage of gas and oil ought to be reduced to the minimum.

a. Exhaust gas: Particular precaution must be taken at the joints of all flanges to prevent the entry of exhaust gas into the interior of the cockpit.

The parts of the airplane near the exhaust, and the cockpit in particular, should either be metallic or protected by fireproof covering (asbestos in sheets or in strands). An air current of at least 2 centimeters is a good insulator.

Exhaust gases ought to be well away from the gasoline manifolds, tanks, pumps, carburetors, and entirely apart from closed spaces where gasoline vapors might accumulate.

In case the exhaust gas is used to warm the carburetor, the manifolds of warm gas ought to be perfectly tight, carefully installed, and the gases discharged far back from the carburetor intake.

b. Ignition apparatus: The high-tension magnetos and their leads are to be inspected very carefully.

Sparks which can flash between the high-tension leads or their adjacent metallic parts and the points where the circuits present a continuous discharge are likely to ignite the gasoline vapors. This, then, is the place to use sure insulations and strong connections provided with safety attachments.

Insulations generally used for the covering of high-tension leads are easily destroyed by the action of heat. If placed near a very hot motor wall, they can melt and short-circuit, frequently causing fires.

The leads ought in no case to pass under the gas pipes.

c. Backfiring: Backfiring is caused by bad functioning of the motor, carburetor, or, more rarely, the ignition. The latter is indeed rare, but can not be completely avoided.

Knowing the gravity of the consequences, the adaptation of the motor to the airplane ought to permit all backfiring without the least danger of fire.

Realizing that the most improved motors still have danger of fire, it is essential to stop or to limit the spreading of the flames in such a manner that they may not reach an inclosure of gas or find inflammable bodies.

For this the following principles should be applied:

(*a*) Either (1) lowering the temperature of gas by wire gauze, or (2) mechanical isolation by automatic valves.

(*b*) Complete evacuation to the exterior of the fuselage of the dangerous flames which the preceding contrivances would have allowed to escape.

For greater security the drawing of air from the motors, which serves at the same time for evacuation of the gases from the return and for the drawing in of fresh air in normal functioning, should bear no communication with the interior of the cockpit. This last disposition is to bear on all installations. Upon the passage of these gases the necessary heating can be arranged.

Wire gauze can be replaced by other coolers, such as the Lelarge device, which operates by subdividing the ignited mixture and the caloric "drainage" by means of aluminum spheres in a box which remains permeable to air.

Evacuation of gas in excess.—When starting the motor and during certain maneuvers in the air, especially in a dive, there is often considerable entry of gas into the air-intake pipe.

It is essential to provide drain nozzles to the exterior, connected to each of the low points of the intake manifold at "relatively" low points, to be determined for the different positions of the airplane (normal flight, climb, glide, or dive). If the carburetor is not leak proof, an overflow outlet tube should be provided at the constant level.

Carburetor and feed.—Carburetors ought to be as air-tight as possible, and the heating of the gases and their speed in the manifolds sufficient for any altitude. Feed ought to be assured in all positions and under all conditions of flight. Feed under pressure should be prohibited because it is too delicate, too sensitive to variations of altitude, and to the amount of gas in the tanks.

Cut-out.—The cut-out should be very accessible and of sure functioning to assure stopping the motors in case of accident in landing.

Tank.—To avoid danger of fire in certain cases of bad landings, the dropable tank mentioned hereafter is interesting.

2. Proper special protection to an airplane in case of war.

There are special dangers of fire to an airplane in case of war proceeding from hits by enemy projectiles. Ordinary projectiles can injure the feed lines and cause leakage of the gas where it is likely to come into contact with the hot parts of the motor. Failure of gas to the carburetor produces back-firing, which is fed immediately by fuel leakage. Incendiary projectiles introduce new and dangerous direct causes of fire.

Every effort should be made to reduce to he minimum the dangerous area and to develop the manifolds. Protection of the fuel tanks is obtained by the following means:

a. A special complete exterior envelope of layers of rubber and Lanser-Dunlop trelliswork, which is nonleakable in spite of perforations. In order for this covering to be effective, the sheet iron making up the tanks should be thin and ought not to be under pressure (another reason for prohibiting pressure feed).

b. Rapid action release cock (30 seconds at the maximum).

c. Dropable tanks designed specially to function in spite of any deformations due to its penetration by a projectile.

For the small reserve tanks protection is obtained by the coverings stated above, by armor plate, or by a double metallic envelope with an inside layer of a special material of the Daigre make.

Propellers.—Propellers ought to be designed for airplanes and motors in such manner as to furnish at the altitude of use and in horizontal flight the maximum power compatible with the operation of the motors at this altitude. The efficiency under these conditions ought to be at least 75 per cent and ought not to fall below 60 per cent for any of the other conditions of flight. With wooden propellers the maximum permissible linear speed at the tip of the blades is 270 meters per second.

As a general rule the coefficient of safety corresponding to the rate of strain of the material ought not to fall below 4 for army corps, reconnaissance, and bombardment airplanes; and not below 3 for pursuit airplanes.

The propellers should be perfectly balanced.

The airplane being placed on the ground, in line of flight, the minmum distance between the earth and the lowest point of the circle swept by the propeller ought to be equal to 0^{m} 25 (d) and, in all cases, higher than 0^{m} 45. (d) representing the distance between the lowest point of the circle swept by the propeller and the point of contact of the wheels on the ground before the landing gear.

Rear propellers should be protected against earth being thrown against them by mud guards placed on the landing-gear wheels or by some other device.

The propeller hubs of the standard type should be sup plied with standard propeller-hub clutch with a view to being started by the mechanical starter. An entire new system of hub motion should be studied by the technical section before adoption.

The manner of attaching the propellers to the shafts ought to be such that assembly and disassembly of the propeller may be effected on the airdrome in less than an hour.

V. ARRANGEMENT OF THE COCKPIT INSTRUMENTS AND INDICATING APPARATUS.

Cockpit instruments are necessarily of regulation types and should be installed in a uniform manner determined by the technical section.

The tachometer, altimeter, watch, and speedometer particularly should be placed on the instrument board according to a well-established arrangement. Provision should also be made to receive, in addition, the different manometers, thermometers, levels, etc., used on an airplane.

The instruments on the board, and the compass also, ought to be entirely visible to the pilot.

They should be easily seen also by the relief pilot. If this can not be done, he should be given an altimeter, a watch, and a compass.

Installation of map cases of the regulation type should be provided for each aviator. The map case should be able to turn in its plane, which should be perpendicular to the line of vision of the aviators.

VI. ARRANGEMENT OF THE ARMAMENT.

A. *Firing through the propeller.*

1. Vickers guns should be set up in such a manner as to permit access, with thick gloves, to all the control levers and to the different parts of the synchronizers. The top plane of the machine guns should be at the height of the shoulder. Their installation should be from 30 to 40 centimeters and the wind shield should be placed in such a manner as not to hinder access, among other things, to the loading handle on the left-hand machine gun.

2. The sights used should be either a telescopic sight or a ring-and-bead sight. A natural line of vision should permit direct aim. The aiming field of these devices should be free from all obstacles. They should be fixed to a rigid part of the airplane in such fashion that vibrations should not bring about any disorder. Aiming ought not to necessitate more than slight movements of the head of the pilot.

3. Disassembly of the machine guns ought to be made in 10 minutes.

The forward and rear axes of fixation ought to be quite accessible. Alignment of the machine guns ought to be done by adjusting parts situated in the rear.

4. A tangent brought from the eye of the pilot to the cowl of the airplane, in the transversal plane of the pilot, ought to make 35° to 40° with the horizontal.

5. Links should be received for at least one machine gun. Cartridge cases should be ejected outside the machine.

6. Cartridge boxes should have a surface minimum of 1,500 square centimeters per machine gun. They should be moveable and their loading extremely easy.

7. Finally, the cowl should be quickly removed and should not be fixed to the rest of the airplane except by swivels or shafts which can be instantaneously removed. The use of bolts should be absolutely forbidden.

B. *Machine-gun tourelles.*

1. Installation of machine-gun tourelles upon reconnaissance and two-seater fighter airplanes:

The type of tourelle to be mounted upon the airplane should be determined by the technical section. Placing of it upon the airplane should be studied before approval.

The field of fire should be as great as possible. It should be at least an angle of 80° upward and the dead angle under the fuselage to the rear should be reduced to the minimum.

The tourelles should be placed so as to interfere as little as possible with the communication between the pilot and the observer. At the side of the pilot, it should not be possible to pass the gun in the low position, but for all other sectors the rotation of the tourelle should permit every possible position of the guns.

The diameter of the base ring of the tourelle is 800 millimeters.

The diameter of the axis or yoke bearing the guns is 920 millimeters. Accordingly, a free space of at least 950 millimeters diameter around the transverse ring is necessary for the passage of the supporting shaft of the guns in the low position.

Vertical firing under the airplane will only be possible for a fuselage having less than 920 millimeters width.

Stops or devices should be provided to prevent the guns from firing into the field of the propeller.

Field limiters are provided for the tourelles in the cases where guns could touch the propellers.

The tourelle ring should be perpendicular to the plane of vertical symmetry of the fuselage and parallel to the line of flight.

The fixed circle of the tourelle is mounted on a wooden circle which should never be omitted.

The points of attachment of the tourelle base to the airplane should provide a suitable mounting upon which the wooden ring may rest. The clamping of the screws or bolts must not involve any deformation likely to hinder the rolling of the tourelle in the transverse circles.

The attaching wires or bolts fastening to the fuselage should never engage the metal part of the tourelle. These wires or bolts should hold only the wooden circle and should be placed at points as far as possible from the places of attachment of the wooden ring with the transverse ring.

As the gunner's belt is fastened to the tourelle the mountings of the transverse ring and the airplane should be capable of resisting a tearing-out strain of 400 kilograms.

The distance between the position of the tourelle ring and the floor should be 950 millimeters.

Balanced tourelles.—Owing to the difficulty of maneuvering tourelles on fast airplanes, the latter should be provided with a device intended to neutralize the effect of the wind blast. This supplementary device should be placed in the fuselage when possible and protected by shields.

The airplane designers should be responsible for the mounting and functioning of these compensating devices.

2. Installation of tourelles on bombardment airplanes:

On airplanes of the bombardment type, generally having very large fuselages, tourelles of 1 meter in diameter or more are provided.

The distance from the position of the tourelle to the floor of the airplane should be from 850 to 900 millimeters.

The technical section will designate the special conditions of the mountings of these tourelles.

Firing under the fuselage.—For permitting firing under the fuselage, steps should be installed in the rear cockpit on each side of the fuselage.

The supports should be mounted in such a manner that the rear gunner can see below the fuselage and fire the lower guns without leaving the tourelle.

The field of fire should include: In the plane of longitudinal symmetry of the airplane, from the vertical downward as far as the tail skid, and from any part of this plane 25° to left and right.

The cross braces of the fuselage should not interfere with firing or with dismounting or reloading.

A trapdoor which can be opened quickly or some other device should be provided to obviate the entry of air into the fuselage.

A device should be provided to prevent the guns from attaining an angle of fire which would be dangerous for the tail of the machine in the course of combat.

C. Installation of Lewis machine gun supports.

In certain particular cases it may be necessary to construct special supports in the airplane.

Gun mounts which are not of standard type or constructed according to the specifications of the military aeronautical authorities should be carefully studied by the technical section before acceptance.

D. Ammunition boxes for the Lewis machine guns.

There should be provided for each tourelle or machine-gun support the regulation number of ammunition boxes corresponding to the number of rounds required.

The magazine racks should be placed in easy reach of the gunner and arranged so as to permit the easy replenishment of the guns during firing.

The general disposition of the ammunition holders for the Lewis machine guns and their installation in the airplane should in each case be approved by the technical section.

All devices supporting movable guns should be easily and rapidly managed and should be furnished with an equalizing system.

Stops or devices intended to prevent the guns from firing into parts of the airplane which might be hit should be provided.

E. Arrangement of bombardment airplanes.

1. Field of visibility and installation of sights:

General requirements.—The pilot and the bomber should be as near as possible to each other and be able to communicate easily by signals and voice without aviophone.

Field of visibility.—Visibility of the pilot: In normal position the pilot should have a field of minimum visibility from 50° to 60° toward the front from the vertical and a lateral field of 15° to right and left. No currents of air should be permitted to enter through the hole made in the floor and a closing should protect the pilot from the light of searchlights on the ground.

Gradometers and inclinometers, visible at night, parallel to the center line of the airplane and placed according to the longitudinal center line of the visibility opening, should be provided.

Visibility of the bomber.

(a) On the exterior of the cockpit.
(b) In the interior of the cockpit.

In the case of a tractor airplane, the bomber requires a field of 75° toward the front, and in addition, in the case of bimotored airplanes or machines of the pusher type, a field of 10° in the rear.

In the case of a tractor airplane, the opening in the floor should have a field of 70° toward the front, attainable with an adjustable seat. In the case of a multimotored air-

plane or machines of the pusher type, they should have a field of 70° toward the front, 10° toward the rear, and in the transversal plane a field of 30° from any part of the center line of the window seat without putting the bomber in an uncomfortable position.

Sights.—Sighting should be provided for either in the interior or the exterior. The best place is on the exterior of the cockpit, at the right. But, when in this position, aiming will not fulfill the conditions of the exposed fields below, or it will be dangerous (neighborhood of the propeller, interference caused by the lower planes); aiming should be provided in the interior.

Exterior.—The field of the sight should be cleared of all obstacles likely to interfere with aiming (wheels, axles, generators, bomb racks, etc.) in a field from 75° forward and 10° backward.

The bomb-rack controls should be placed in easy reach of the bomber while operating the sights.

Interior.—The sight should be placed in the front part of the cockpit on bimotor airplanes. It will have a field of fire provided for in the preceding paragraph on the bomber's visibility. It will be placed in such manner that it may be used without trouble by the bomber. An articulated device should fold it down when not in use, clearing the position of the bomber. The bomb-rack controls should be in reach of the hand during sighting, preferably at the right. The sighting hole should be capable of being cleared entirely of all transparent substance for aiming at night.

2. From the point of view of bomb racks: All airplanes should be designed in conformance with specifications, using standardized bomb racks determined upon by the technical section.

These bomb racks differ according to the nature of the projectiles carried and can be classed as follows:

1. Bombracks G. P. for bombs of 100 or 200 kilograms. These are carried horizontally under the wings or under the fuselage.
2. Special bombracks for bombs of 500 or 1,000 kilograms, being carried horizontally under the fuselage.
3. Horizontal bombracks, Michelin No. 3, carrying all present projectiles from 10 to 100 kilograms, mounted in the wings.
4. Vertical bombracks for bombs of 50 kilograms, being carried in the interior of the fuselage.
5. Vertical bombracks for bombs of 10 kilograms, being carried like the preceding.
6. Horizontal Michelin bombracks for bomb flares, being carried under the wings (two bombs) or on the vertical sides of the fuselage (one bomb).

Bombracks G. P.—G. P. bombracks for bombs of 100, 200, 500, and 1,000 kilograms are of a standard type. Examples of mounting can be furnished by the technical section upon request.

Horizontal bombracks.—Michelin horizontal bombracks are made in 32 or 40 cells and carry either a number of 10-kilogram bombs corresponding to the number of cells, or one of 50 kilograms in place of every four of 10 kilograms; or one of 100 kilograms in place of every six of the 10-kilogram bombs.

Vertical bombracks.—Bombracks for vertical bombs of 50 kilograms are made for 4, 5, 8, and 10 bombs, grouped upon a single row of 4 or 5 bombs, or upon two braced rows (216 millimeters square, sideways, per bomb).

Vertical bombracks for bombs of 10 kilograms, with equal bulk, carry four times more projectiles. These vertical bombracks are compartmented boxes whose dimensions depend on the number of bombs (216 millimeters square, sideways, per bomb of 50 kilograms or for four bombs of 10 kilograms). They should be supported by a special framework for 50-kilogram bombs and for 10-kilogram bombs.

The bulk of the 50-kilogram vertical bombracks is about 0^m 35 on top of the frame and 1^m 10 on the bottom of the frame. The bulk of the 10-kilogram vertical bombracks is about 0^m 20 on top of the frame and 1^m 10 on the bottom of the frame.

They should be easily removed from the lower part of the fuselage.

The minimum space between the spars of the wings of airplanes receiving bombs in the fuselage should be 1^m 100 (dimension taken on the interior of the spars).

The release mechanism on the top part of the bombracks should not be joined with the top structure of airplane and should be easily accessible. Lateral inspection doors should be provided in communication with those of the bombracks.

With the airplane resting on its tail skid, the distance from the ground under the spars of the lower wing should be 1^m 30 at the minimum in the case where 50-kilogram bombs are to be placed in the interior of the fuselage.

The under part of the lower wings and of the fuselage between the wheels of the landing gear in the bimotored planes should be absolutely free from all cables, tubes, or other encumbrances likely to interfere with the suspension or fall of the bombs.

In the monomotored planes, the lower plane should be free of any obstructions immediately underneath, between the wheels of the landing gear.

Control positions.—Release handles of the bombracks upon the bimotored airplanes should be on the right side of the front cockpit, mounted so that bombs can be released while sighting either in the interior or on the exterior.

Auxiliary controls should be provided near the pilot.

Control of the bombracks is generally done by a bare cable over a pulley or through a copper tube.

Passages.—The passage for going from the front cockpit to the rear and giving access to the bombracks should be 400 millimeters wide at a minimum. The height from the floor of the passage under the top structure should permit the passage of a man without difficulty.

Passage from the bomber's position to the pilot's cockpit.—Cross structures between the pilot's post and the forward post ought to be avoided as much as possible or at least should be high enough so that the passage may be made without difficulty or interference with the pilot.

The technical section will communicate to the constructors of bombardment airplanes the detailed characteristics of the above material and also the detailed conditions of assembly.

VII. ARRANGEMENT OF ELECTRICAL EQUIPMENT.

Generators.—All motors are designed to drive electric generators. The installation of generators should consequently be provided for on all airplanes.

If the operation is made by driving belt, it should be provided with a tightening pulley arrangement permitting the taking up of the elongation of the belt.

The cowling should bear an inspection door for the generator, permitting the changing or regulating of the belt and the changing of the generator.

The speed of the generator should be regulated by a governor. The connection wires should be studied with a view to rapid mounting on an airplane in service and should not be mounted in the shop.

Metal fittings.—Provision must be made for attaching the wires of the various devices requiring electrical energy specified hereafter:

a. Wireless.
b. Heat for the passengers.
c. Warming up the machine guns.
d. Equipment for night flying.

Installation of the wireless.—The wireless should be installed to permit functioning in direct or in indirect excitation by simple management of the commutators.

The antennæ wheel should be placed beside the observer's seat in such fashion that it can be wound up or unwound easily with the right hand. He should be able to do this with ease.

The outlet tube of the antennæ should be placed so that its unwinding may be made in the same manner on all airplanes.

The wheel should be placed outside the observer's place.

The transmitters should be secured by the aid of very solid attaching fittings, assuring perfect rigidity during manipulation.

Commutators and adjusting arrangements for the wireless should be placed in reach of the observer and should be arranged for easy management.

The transformer and a voltage regulator should be placed where it is sheltered from the gas vapors.

The receiving apparatus and the storage batteries should be easily removable. They may occupy the place of the photographic outfit.

Night equipment.—Landing lights should be adjustable fore and aft by means of a rigid control managed by the pilot.

The location of the navigating lights should be such that the lights may be quite visible to the observer and at the same time may determine the exact position of the airplane for neighboring airplanes. The navigation lights should be streamlined.

The storage batteries should be removable to permit recharging the battery on the ground.

VIII. PHOTOGRAPHY ARRANGEMENTS.

Airplanes should permit the use of cameras in the conditions provided for their class.

In addition to the general visibility necessary to the management and defense of the airplane, it is necessary that the pilot in horizontal flight can see, under the most favorable angle, the ground from the vertical to 30° forward. This may be done directly by a window, ground glass, diverging lens, by a periscope, or some other apparatus whose bulk will not interfere with movements.

Moreover, the observer should see all the field which escapes the pilot. This may necessitate leaning over the side.

The placing of the camera should be such that its operation does not require the neglect of the surveillance of the sky.

The photographic machine should be in shelter from oil spray and it should not project beyond the fuselage.

It ought to be sufficiently accessible to allow hand adjustments for loading, change of plates, or any adjusting necessary. It should be possible to do this easily with hands covered with heavy gloves, for the largest magazine used in loading the camera.

The installation should take into account the location of the photographic magazines for replacement purposes for the types which are in service.

IX. MISCELLANEOUS ARRANGEMENTS.

Parachutes.—All airplanes should be arranged for receiving as many parachutes as persons. Ability to use the parachute should be one of the first conditions imposed for the arrangement of the interior. A placing of the pilot analogous to that of the Salmson is not permitted in a war machine.

Oxygen apparatus.—Installation of oxygen apparatus should be provided for in all machines.

Cables.—Each machine should be furnished with a device permitting the machine to be towed by mechanical traction and a device permitting the tying down of the machine in case no hangars are available.

FRENCH TYPE SPECIFICATIONS.

The French aeronautical authorities realized late in 1919 that it was necessary to formulate a definite program for the development of military aircraft. The delay in working up a program was due primarily to the fact that France was so stunned at the end of the World War that it was necessary for her to remain dormant until she could ascertain what her future military problems would be. However, she went to work in a very logical way and determined what kind of planes would be necessary in order to insure proper defense. This resulted in definite conclusions in which type specifications were drawn up. The present French technical program is still based primarily on these specifications.

Study and comparison of the French specifications with our own are not only interesting but should be carefully considered in any revision of our requirements. A table showing the various French types with the requirements for each type follows. In addition, each type is considered in minute detail, giving the general requirements, armament, fuel, equipment, and characteristics.

In these tables where the French refer to the military load, they mean passengers, armament, and equipment. The fuel supply is measured in hours running with the motor turning at full speed under sea-level conditions.

Table of type specifications.

Type.	Military load.	Hours gas.	Ceiling, theoretic.	Ceiling, normal.	Speed, ceiling.	Speed, sea level.	Remarks.
	Kilograms.		*Meters.*	*Meters.*	*Kilometers per hour.*	*Kilometers per hour.*	
Pursuit:							
C.1	220-270	2½-3	9,000	7,000	240	120	Monoplace pursuit for high altitudes.
c.1	220-270	2½-3	6,500	4,000	270	120	Monoplace pursuit for low altitudes.
Pursuit and reconnaissance:							
C.Ap.2	400	4	8,500	7,000	200	110	Biplace pursuit or reconnaissance.
CAn.2	400	4	6,000	3,000	190	90	Biplace pursuit and night reconnaissance.
Observation:							
A.2	450	3	6,000	1,000-3,000	200	90	Biplace, C. A., and divisional.
Ad.2	450	3	6,000	1,000-3,000	200	90	Do.
Ab.2	350	2½	4,500	1,000	180	80	Armored biplace for divisional squadrons.
Bombardment:							
Bp.2	580	7	7,500	5,000	190	90	Biplace, day bombardment, long distance.
BS.2	720	4	5,000	1,000-2,000	200	100	Biplace bombardment or attack.
Bpr.3	520	6	7,500	5,000	210	100	Triplace of protection for the day bombardment.
Bn.2	940	4	4,000	2,000	150	80	Biplace, lightly loaded for day bombing and combat.
Bn.4	2,220	7	4,500	2,000	150	80	Multiplace, heavily loaded, night bombardment, long distance.
Colonial	750	6	4,500	2,000	160	75	

PURSUIT.

Monoplace pursuit for high altitudes—Airplane C. 1 type.

General requirements.—This airplane should be easily managed, very strong, very rapid in maneuvering, and able to dive at great speed.

It is indispensable for the pilot that visibility should be as perfect as possible as a condition of first importance for combat and for formation.

It seems that this can be obtained either by the construction of a parasol type monoplane (Morane or Gourdou fashion), or by stagger of the wings in the biplane cellules.

In all cases it is necessary—

1. That the top plane be at the height of the pilot's eyes.
2. That a line passing through the eye of the pilot and the leading edge of the lower plane should make at least an angle of 15° with the vertical.
3. That the slope at the rear of the lower planes permit the pilot to see straight down.
4. That the section of the fuselage and cowling of the fuselage be studied to reduce the dead angle due to the fuselage and to the motor.
5. That the height of the pilot's seat be regulated and provision be made for the pilot to turn himself easily upon the seat.

The airplane should be furnished with a removable armor plating protecting the pilot from the rear.

The motor should be capable of automatic starting.

Armament.—Two rapid-firing guns, synchronized, or preferably a rapid-firing gun and an automatic cannon, are required. The guns may be, at will, either 7.65 or 1 millimeter caliber; 800 cartridges per gun, 30 projectiles for the cannon.

Fuel.—Tanks for three hours' fuel for the motor turning at full speed at sea level.

To avoid excessive weight, it is suggested and preferred to have gasoline rip panels on the bottom of tank to assure emptying of tank in case of fire rather than leak-proof tanks.

Equipment.—The airplane should have provision to provide warmth for the pilot, for installation of oxygen apparatus, Very pistol, automatic photographic apparatus, parachute, and, eventually, interairplane telephones.

Characteristics.—Ceiling, 9,000 meters. Speed at 7,000 meters, 240 kilometers per hour. Minimum speed at sea level at most favorable angle, with motor throttled, 120 kilometers per hour.

Military load of 220 kilograms in case of two machine guns; 270 kilograms in the case of a cannon and one machine gun.

The weight of the pilot's armor is not included in the useful load as listed, which comprises the pilot, machine guns and cannon, their supports and ammunition, oxygen apparatus, instruments, heating equipment, interairplane telephone, Very pistol, and parachute.

Single-seater fighter for low altitudes—Airplane c. 1.

General requirements.—This airplane should have the same qualities of management, or solidity, as the monoplace C. 1, and it should offer the pilot the same visual field.

The realization of this monoplace for low altitudes has no special interest except that the airplane possesses, at 4,000 meters, a considerable superiority of maneuverability and speed over the monoplace C. 1 (a difference of speed of about 15 kilometers).

Armament.—Same as for airplanes C. 1 type.

Fuel.—Same as for airplanes C. 1 type.

Equipment.—Same as for airplanes C. 1 type, except the oxygen apparatus.

Characteristics.—Ceiling, 6,500 meters. Speed at 4,000 meters, 270 kilometers per hour; minimum speed at sea level, with motor throttled and at most favorable angle, 120 kilometers per hour.

Military load, 220 kilograms in the case of two machine guns or 270 kilograms in the case of a cannon and a machine gun. The weight of the armor is not included in the military load.

PURSUIT AND RECONNAISSANCE.

Biplane pursuit and reconnaissance—Airplanes C. Ap. 2 type.

General requirements.—Designed specially for evolutions at high altitudes (7,000 meters). Visibility should be perfect for the pilot and for the passenger. The observer, normally seated, should see 30° forward and vertically.

Pilot and passenger, at the maximum distance, should be able to communicate by sight and voice without aviophone.

The airplane should be capable of fast maneuvers, easy for average flying.

The motor should be particularly reliable in order to give the pilot the necessary confidence for distance missions.

This airplane can be realized with motors of 500 or more horsepower. These motors can not be counted upon for 1920.

The motor for use, then, will be a motor of lower horsepower, furnished with a device permitting the conservation of power at high altitudes. This will have the advantage of permitting the realization of a machine more maneuverable, although less powerful.

The interior arrangement should be complete and very comfortable.

The airplane will be designed for receiving, if necessary, two armored seats. The tanks will be protected or easily detachable. The airplane will have double controls or provided with an easy passage from the passenger's cockpit to the pilot's seat.

Armament.—The field of fire for the observer should be free to the maximum, particularly toward the rear and downward.

An arrangement should be provided for the installation of a floor gun shooting underneath and to the rear.

PURSUIT TYPE.	RECONNAISSANCE TYPE.
One or two machine guns, synchronized, or a cannon. Two machine guns joined together, on the tourelle, or an automatic cannon (in no case should such an airplane fly armed with two cannons). Five hundred cartridges per machine gun forward, 800 for the machine gun in the rear, 300 projectiles for the cannon.	A synchronized gun, two machine guns, connected together, on the tourelle, 300 cartridges each.

The forward machine guns can be either 7.65 or 11 millimeter.

Fuel.—Tanks for four hours' fuel for the motor turning at full power at sea level. One-fourth of the total capacity of gasoline will be contained in a removable tank provided with facilities for dropping quickly.

Equipment.—The airplane will be arranged to provide heat for the personnel and, eventually, the machine guns; the installation of an oxygen apparatus for the entire crew, an arrangement for Very pistols, and the installation of two parachutes.

PURSUIT TYPE.	RECONNAISSANCE TYPE.
The installation of photographic apparatus, moving picture or automatic. Eventually, interairplane telephones.	Installation of photographic apparatus, of 50 and 120, with a minimum of 100 plates. The installation of a ground glass for visual reconnaissance.

Characteristics.—Ceiling, 8,500 meters. Speed at 7,000 meters, 200 kilometers per hour; minimum speed at sea level, motor throttled and at most favorable angle, 110 kilometers per hour.

Military load, 400 kilograms.

In the military load are included only the pilot, the observer, the parachutes, machine guns, cartridges, machine-gun supports, airplane instruments, oxygen apparatus, photographic apparatus, heating arrangements and their supports, the ground glass and its support, the interplane telephone, and the container for the Very pistols.

Biplace pursuit and night reconnaissance.—Airplanes C. An. 2 type.

General requirements.—This airplane should not be cumbersome (maximum wing spread of about 15 meters).

It should be a very good glider, landing slowly, well balanced, easily maneuvered, and supersensitive fore and aft.

The visibility should be as good as possible, particularly toward the front and downward.

The pusher type is not prohibited.

The pilot and the observer, at the maximum distance, should be able to communicate by sight or voice without aviophone.

The airplane should have double controls or an easy passage from the observer's seat to the pilot's cockpit.

The motor will be furnished with an effectual silencer.

Tanks should be protected or easily detachable.

This airplane can be realized with motors of about 400 horsepower.

Armament.—Two or three machine guns, synchronized (caliber 7.65 or 11), firing 2,000 cartridges per minute; or, preferably, a machine gun and a cannon, two twin machine guns on the tourelle, or an automatic cannon.

No airplane will be equipped with two automatic cannons. One thousand cartridges per forward machine gun, 800 per machine gun on the tourelle, and 30 projectiles per cannon should be furnished.

Fuel.—Tanks for four hours' fuel supply for the motor turning at full speed at sea level.

Equipment.—The airplane will be arranged to provide heat for the personnel and, eventually, of the machine guns; night lighting and the use of a searchlight; installation of two parachutes; the installation of wireless (sending and receiving) with a view to regulating artillery fire; the use of instruments of goniometry; the installation of bomb flares; the installation of an arrangement for Very pistols.

Characteristics.—Ceiling, 6,000 meters. Speed at 2,000 meters, 195 kilometers per hour; speed, minimum, at sea level, motor throttled, at the most favorable angle, 90 kilometers per hour.

Military load, 400 kilograms and 450 kilograms if the armament includes a cannon.

In the military load are included only the pilot and observer, the machine guns, the cartridges, the machine-gun supports, the airplane instruments, wireless, heating apparatus, lighting apparatus, parachutes, and the instruments of goniometry, pistols, and signal guns.

OBSERVATION.

Biplaces, C. A. and divisional.—Airplane A. 2 and Ad. 2 type.

General requirements.—The airplane should be very maneuverable, and controls should offer a minimum of fatigue to pilot from sea level to 4,000 meters.

The span should not exceed 15 meters.

The airplane should have a very solid chassis and be so constructed as to resist bad landings.

It should have a speed range of two to one and should be able to take off very quickly.

The pilot and observer should be as close together as possible and should be able to communicate by voice and sight without aviophone.

The visibility of the pilot and observer should be studied from a standpoint of ground observation when at low altitudes.

It should have, if possible, a special adaptation of motor for divisional squadron types.

The airplane should be designed to accommodate two armored seats, dual control or passage facility from the observer's cockpit to pilot's cockpit, rubber-covered tanks or detachable tanks, and the control cables should be doubled with different points of attachment.

This type ought to be provided with a motor of from 300 to 400 horsepower.

Armament.—One synchronized machine gun, two tourelle machine guns, one floor gun shooting underneath and to the rear, 500 cartridges per gun, and removable bomb rack for 100 kilograms of bombs.

Fuel.—Three hours' fuel at sea level.

Equipment.—The airplane should have provision for wireless (sending and receiving), Klaxon warning apparatus, heat for the occupants and eventually of machine guns, oxygen installation, two parachutes, two Very pistols, and 20 Very pistol cartridges.

PHOTOGRAPHY.

AIRPLANE C. A.	DIVISIONAL AIRPLANE.
Installation provision for photographic outfit, vertical and oblique, 26 and 50 and for photographs, vertical, of 120, minimum of 50 exposures.	Installation provision for vertical and oblique photographic outfit of 26 and 50, and also for installation of automatic and moving-picture apparatus.

A folding observer's seat should be installed and also a container for message blanks at the disposition of observer.

The wireless installation and photo outfit installation should be compatible solely with the use of the wireless with direct excitation.

At all times for other wireless arrangements it is indispensable that the changing of these equipments will not require more than three hours for two mechanics.

Characteristics.—Ceiling, 6,000 meters. Speed at 2,000 meters, 200 kilometers per hour. Minimum speed at sea level, at most favorable angle, with throttled engine, 90 kilometers per hour.

Military load, 450 kilograms.

In these weights are included pilot, observer, parachutes, machine guns, oxygen apparatus, cockpit instruments, Very pistols, Very ammunition, photographic installation and supports, wireless outfit and heating outfit.

Armored two-place for divisional squadrons—Airplane type Ab. 2.

General requirements.—Type Ab. 2 should be very maneuverable. It should be capable of executing a complete figure "eight" at 100 meters between two points 100 meters apart without losing altitude.

It must be armored against normal shots fired at 300 meters range from underneath, behind, and from the sides.

It is understood that all equipment, including motor, motor accessories, radiator, and wireless, must be armored, also gas tanks, if not installed as per system of the Lanser type.

All control cables should be doubled and far enough away from one another throughout their length so as not to be severed by one projectile.

All vital members shall be studied to diminish risk of rupture from rifle fire.

The pilot and observer should be located as close together as possible and capable of communicating with each other by sight and voice without aviophone.

Visibility to both should be such as to permit good ground observation at low altitudes.

The plane should have dual controls, or facility for passage of observer to pilot's cockpit.

Armament.—One synchronized machine gun, two tourelle guns permitting of interplane combat fire or ground fire, one floor machine gun permitting firing underneath fuselage with good sighting, facilitating accurate ground fire, 500 cartridges per gun.

Fuel.—Two and one-half hours' fuel for motor running at full power at sea level.

Equipment.—This type should have arrangements for wireless (receiving and sending), auditory warning apparatus, heat for the occupants and eventually of guns, two Very pistols and ammunition. The comfort of the observer gunner should be specially studied, as for type A. 2.

This type should permit of installation of photographic apparatus, automatic or motion-picture (opening to be closed by removable armor plate).

Characteristics.—Ceiling, 4,500 meters. Speed at 1,000 meters, 180 kilometers per hour; minimum speed at sea level, motor throttled, at most favorable angle, 80 kilometers per hour.

Military load, 350 kilograms (armor not included).

In this military load are included only the equipment, machine guns, cartridges, supports and tourelles, cockpit instruments, Very pistols and ammunition, wireless apparatus, heating and photographic outfits.

Coefficient of safety in static tests, the same as for airplane type A. 2 under the same conditions.

BOMBARDMENT.

Biplace for day bombardment, long distance—Airplane Bp. 2 Type.

General requirements.—This airplane should be designed for group evolutions at an altitude higher than 5,000 meters.

Its speed should be little inferior to that of the biplace pursuit planes.

The motors should be furnished with self-starters.

Being given duties of long duration to accomplish, the pilot and observer should be comfortably installed.

A turning seat at a regulated height will be planned to permit the observer to see the sky and the ground while remaining seated.

The pilot and bomber, brought together as nearly as possible, ought to be able to communicate by sight and voice without the aviophone.

The airplane will carry double controls or else have easy passage from the passenger's post to the observer's.

The field of vision of the pilot and of the bomber will be particularly studied for group flying, for surveillance of the sky, and for the search for an objective. The field of vision forward on the vertical should be 45° for the pilot and 75° for the bomber.

Rip panels for the tanks and two armored removable seats should be provided.

Controls should be double, with different points of attachment.

Armament.—A machine gun, synchronized; two twin machine guns on the tourelle; 500 cartridges per gun: installation provided for floor machine gun, firing below and to the rear.

Bombs.—The airplane should be able to carry 200 kilograms of bombs with complete load of fuel. Besides, it should be arranged with removable bomb racks for a weight of projectiles corresponding to one-fourth of the fuel and weight of the removable tanks.

The bomb racks should be able to permit the easy change from one to the other of the following loads:

1. Entire load of bombs of 10 kilograms (incendiary or fragmentation).
2. Entire load of bombs of 50, 100, or 200 kilograms.

Fuel.—Tanks for seven hours' fuel for the motors at full speed at sea level, one or several tanks representing about one-fourth of the total capacity, should be easily removable.

Equipment.—The airplane should be arranged to permit vertical photography from 50 to 120; installation of an automatic or moving-picture camera for vertical photography or oblique toward the rear (for photographing the results of bombardment); heat for the pilot and passenger and eventually of the machine guns; installation of oxygen apparatus; two parachutes; and eventually of night lighting equipment and interairplane telephone.

Characteristics.—Ceiling, 7,500 meters. Speed at 5,000 meters, 190 kilometers per hour; minimum speed at sea level, at most favorable angle, with motor throttled, 90 kilometers per hour.

Military load, 580 kilograms.

In this military load are included only the pilot, observer, machine guns, cartridges, machine-gun supports, cockpit instruments, bomb racks, bombs, oxygen apparatus, parachutes, photographic and heating outfits, their supports, and interairplane telephones.

Biplace bombardment and attack—Airplanes BS. 2 type.

General requirements.—This airplane should not be cumbersome (wing spread of about 18 meters). It is not necessarily single-motored.

It should possess strong landing gear, capable of resisting bad landing fields.

The speed of its take-off should be sufficient for using improvised landing fields.

The one or two engines should be equipped with self-starters.

The pilot and observer should be as near together as possible and able to communicate by sight and voice without aviophone.

The airplane should carry double controls or should have easy passage from the observer's cockpit to that of the pilot.

Visibility for the pilot and observer should be perfect ahead and toward the ground.

Comfort and interior installation will be specially studied.

All controls should be doubled with separate points of attachment.

Tanks should be protected or easily detachable.

ARMOR.

BOMBARDMENT.	ATTACK.
Two removable armored seats.	Two removable armored seats, more removable armored plates protecting the engine underneath and the personnel against normal shots, resisting perforation at more then 400 meters altitude.

ARMAMENT.

BOMBARDMENT.	ATTACK.
A synchronized gun, two twin machine guns on the tourelle, installation provided for a floor gun firing underneath and toward the rear, 500 cartridges per gun.	For the use of the pilot: Two machine guns arranged for easy and effective attack on objects on the ground. For the use of the observer: Three machine guns permitting effective attack on objects on the ground, two or less of the machine guns should permit firing in aerial combat. Munitions supply should permit the execution of continuous firing for one minute.

The field of firing will be specially studied to permit firing toward the ground with easy aim on land objectives.

BOMBS.

BOMBARDMENT.	ATTACK.
The airplane should be able to carry 300 kilograms of bombs. The bomb racks should permit easy change from one to the other of the following loads: 1. Entire load of bombs of 10 kilograms. 2. Entire load of bombs of 25 and 50 kilograms.	The airplane should be able to carry 100 kilograms of bombs, fragmentation. These bombs can be released either by the pilot or the observer.

It is possible to adapt this type of airplane to the two different functions by providing for the installation of equipment necessary for the two types of work.

Fuel.—Four hours' fuel for the motors turning at full speed at sea level. One-fourth of the total capacity of gasoline should be contained in a tank which is easily removable. For missions of attack, this tank should be removed.

Equipment.—The airplane should be arranged to permit the installation of two parachutes, installation of an apparatus for Very pistols, heat for the occupants and eventually of the machine guns, the eventual installation of interairplane telephone and lighting outfits, automatic camera or motion-picture camera for vertical photography and at an angle toward the rear.

Characteristics.—Ceiling, 5,000 meters. Speed at 2,000 meters, 200 kilometers per hour; minimum speed at sea level, motor throttled, and at the most favorable angle, 100 kilometers per hour; time of climb to 3,000 meters, 20 minutes.

Military load, 720 kilograms (armor not included).

In this military load are included only the equipment, machine guns, cartridges, supports and tourelles, bomb racks, view finders, cockpit instruments, Very pistols and ammunition, heating and lighting apparatus, and interairplane telephone.

Triplace for protection of day bombardment—Airplane Bpr. 3 type.

General requirements.—This airplane is intended for close protection of bombardment airplanes, type BS.2 or Bp.2, and eventually of airplanes, type A. 2, observation.

It should possess the maneuverability indispensable to an airplane which will have to sustain defensive combats.

It should have great speed of take-off for facilitating its missions of protection.

Its armament should be very powerful, its field of fire perfectly free. Three removable armored seats should be provided, tanks should be protected or easily detachable. Controls should be double with separate point of attachment.

The airplane should have double controls for use of one of the observers or easy passage from the gunner's post to that of the pilot. One of the gunners should be placed as near as possible to the pilot (communication by voice without aviophone).

The motors should be furnished with automatic starters.

Armament.—Twin machine guns on the tourelle forward with field of fire toward the rear, firing at a minimum of 15° above the horizontal (in line of flight); twin machine guns on the rear tourelle; two machine guns, twin, firing under the fuselage toward the rear, with a window permitting aim and sight in this direction; 500 cartridges per gun.

One of the pair of machine guns can be replaced by an automatic cannon.

This airplane will not carry bombs by reason of its armor. The removable bomb racks, however, ought to allow a contingent load of 250 kilograms.

Fuel.—Six hours, of which one-third is in the tanks which are easily removed.

Equipment.—The airplane will be arranged to permit vertical photography and oblique toward the rear with automatic or motion-picture camera, heat for the pilot and passengers and eventually of the machine guns, the installation of Very pistols, three parachutes, eventually interairplane telephones and lighting outfits.

Characteristics.—Ceiling, 7,500 meters. Speed at 5,000 meters, 210 kilometers per hour; minimum speed at sea level, motor throttled, and at the most favorable angle, 100 kilometers per hour.

Military load, 520 kilograms without the armor.

In this military load is included only the pilot, passengers, machine guns, cartridges, supports and tourelles, oxygen apparatus, cockpit instruments, heating apparatus, photographic outfits and their supports, parachutes and interairplane telephones.

Biplane, lightly loaded for day bombing and combat.—Airplane type Bn.2.

General requirements.—This airplane should be relatively of small bulk (wing spread of about 20 meters).

It should be a good glider, well balanced, automatically placing itself in descent or ascent according to the variations of the operation of the motors.

It should be furnished with strong landing gear, should have great speed of take-off from the ground in order to be used at need on improvised landing fields.

Visibility should be perfect toward the front and below. Pusher type motor is not prohibited.

The pilot and observer should be as close together as possible and should be able to communicate by sight and voice without aviophone.

The airplane should carry double controls or should have easy passage from the cockpit of the observer to that of the pilot.

The motors should be easily managed, sure, and silenced.

Intended for bombarding unprotected targets, it should be able to descend very low for the bombardment and to zoom up and climb rapidly.

Tanks should be protected or easily detachable.

Armament.—Two twin machine guns on the tourelle for use of the observer; a machine gun firing below, toward the rear; 500 cartridges per gun. The machine guns should permit firing upon objects on the ground.

The airplane should be able to carry 500 kilograms of bombs with four hours' fuel; besides, it should be furnished with removable bomb racks for a weight of projectiles corresponding to one-fourth of the fuel; the bomb racks should permit the easy change from one to the other of the following equipments:

1. Entire load of bombs of 50 kilograms each.
2. Load of bombs, half of 10 kilograms and half of 50 kilograms.
3. Load of bombs, half of 50 kilograms and half of 100 kilograms.

Fuel.—Tanks for four hours' fuel for the motors turning at full speed at sea level.

Equipment.—The airplane should be arranged to permit lighting for night and, eventually, the use of a searchlight for landing, heat for the crew and, eventually, of the machine guns, installation of two parachutes, use of the apparatus of goniometry, installation of bomb flares, installation of an arrangement for signaling by Very pistols.

Characteristics.—Ceiling, 4,000 meters. Speed at 2,000 meters, 150 kilometers per hour; minimum speed at sea level, motor throttled, and at the most favorable angle, 80 kilometers per hour.

Climb to 2,000 meters in 20 minutes.

Military load, 940 kilograms.

The military load comprises only the crew, machine guns, cartridges, supports, tourelles, bomb racks, view finders, cockpit instruments, heating and lighting apparatus and that of goniometry, Very pistols and ammunition.

Heavily loaded multiplace for long-distance night bombardment—Airplane Bn. 4 type.

General requirements.—Designed for carrying the greatest load possible a distance of 200 kilometers. Mobility is a secondary quality. The wing spread is not limited, provided the wings are easily demountable to permit the shelter of the airplane under a hangar 26 by 28 meters.

The airplane should be equipped for four people—a pilot, a pilot's aide, a bomber, and a mechanic. A runway in the fuselage should permit easy passage from one post to another.

The airplane should be at least trimotored and should be able to take off with one motor cut out. The motors should be accessible in flight.

It should be furnished with an effective silencer and an automatic starter.

The field of vision ought to be perfect, especially toward the front and below.

Tanks should be protected or easily detachable.

Armament.—Two machine guns upon the forward tourelle; two machine guns on the rear tourelle; two machine guns under the fuselage toward the rear, with a window permitting sight and aim. Five hundred cartridges per gun.

The supports of the machine guns should permit firing at objects on the ground.

The airplane should be able to carry 1,500 kilograms of bombs when it carries only six hours' fuel. Besides, it should be furnished with removable bomb racks for a weight of projectiles corresponding to one-fourth of the gasoline and to the weight of the removable tanks.

The bomb racks should permit of easy change from one to the other of the following equipments:

1. Entire load of bombs of 100 and 200 kilograms.
2. Load, half of bombs of 50 kilograms and half of bombs of 100 and 200 kilograms.
3. Load with three bombs of 500 kilograms.
4. Load of one bomb of 1,000 kilograms and one bomb of 500 kilograms.

Fuel.—Tanks for seven hours' fuel for the motors turning at full speed at sea level; one or several tanks, representing about one-fourth of the total capacity, should be easily removable.

Equipment.—The airplane should be arranged for permitting lighting for night and the use of a searchlight for landing; heat for the crew and, eventually, the machine guns; installation of four parachutes and of wireless (receiving and sending); the use of apparatus of goniometry; installation of bomb flares; and an arrangement for Very pistols and ammunition.

Characteristics.—Ceiling, 4,500 meters. Speed at 2,000 meters, 150 kilometers per hour; minimum speed at sea level, motor throttled, and at most favorable angle, 80 kilometers per hour. Climb to 2,000 meters in 20 minutes.

Military load, 2,220 kilograms.

In the military weight are included only the crew, machine guns, cartridges, supports and tourelles, bomb racks, bombs, view finders, cockpit instruments, heating and lighting outfits, wireless and goniometry, pistols and Very pistols.

Colonial type airplane.

General requirements.—The airplane ought to have an easy landing and to realize a sufficient speed at the altitude of use in order not to be troubled by normal winds.

Its radius of action ought to be extensive on account of the cost and the difficulties of establishing refueling stations.

It should be able to be transformed quickly into a bombardment plane.

Its construction should be particularly looked after and one should seek specially—

1. Good preservation in normal conditions of temperature and of hygrometric degree, either the temperatures currently reaching 40° and 1 hygrometric degree variant of 30 to 35 in western Africa to 70 to 90 in the other colonies.
2. Absolute interchangeability of demountable parts and, if possible, of part assemblies.
3. Maintenance and easy repair.
4. Bulk reduced for transport (ease of assembly and disassembly).
5. Very solid landing gear and pneumatic tires resisting the special conditions of temperature and humidity.

Motors can be cooled by air or by water, taking account, in their choice and their mounting, of the special conditions of their functioning and their preservation—temperature, humidity, sand, etc. They should be strong, easy to repair and maintain, and easy of access.

The airplane should be polymotored and should be able to continue its mission with one motor cut out. The motors should be very easy to start.

Armament, contingent.—Two machine guns, front, movable, firing downward; one machine gun, rear, firing downward; 500 cartridges per gun.

The airplane should be equipped to carry 300 kilograms of bombs of 10 kilograms each.

Fuel.—Six hours for motors at full speed at sea level.

Equipment.—The airplane should be arranged to permit night lighting, installation of one parachute for the observer, installation of wireless (sending and receiving), and one photographic apparatus of 50.

Characteristics.—Ceiling, 4,500 meters with full load. Speed at 2,000 meters, 160 kilometers per hour; minimum speed at sea level, 70 kilometers per hour.

Military load, 750 kilograms.

The machine should be able to take in eight persons, flight equipment included. Arrangement should be provided in consequence.

GENERAL REMARKS.

Power of fire.—It is well understood that the directions given on the number of machine guns constituting the armament exacted are valued only as an indication of the power of fire exacted.

If a single machine gun lighter than two Lewis guns can give the same power of fire with the same safety of functioning, the constructor can propose its adoption. The unit of comparison adopted is, for the forward guns, the Vickers: for the rear guns, the Lewis.

Armor.—The armored seats and removable armor plates should be studied in such a fashion as to obtain the maximum safety without surpassing a weight of 50 kilograms per person or per motor.

Radiators for the machine guns.—The machine guns intended for firing upon objects on the ground, on the airplanes of types A. 2, BS. 2, or Bn. 2, should be provided with special radiators around the barrel of the gun, permitting it to fire long series of cartridges without risking the deterioration of the gun.

FRENCH AERODYNAMIC STUDIES.

Aerodynamic studies have been given considerable more importance throughout Europe since the war. The French are conducting their aerodynamic experiments at the present time in the wind tunnel at the Eiffel Tower and at the old St. Cyr Tunnel. Both places offer fairly good facilities for the conducting of aerodynamic tests. The Eiffel Tower Tunnel is well known and complete description of the St. Cyr Tunnel is available among our technical files.

A new aerodynamic station is being constructed at Issy des Moulineux, which is located on the outskirts of Paris. The entire station is constructed of brick and steel and will have adequate facilities for the conducting of aerodymanic tests and all kinds of experimental work. Provision has also been made to have a flying field available in the near future, adjoining this station.

A large headquarters, hangars, engine test stands, dynamometers, and buildings to house every known device for testing materials, have been constructed. However, by far the most interesting building on this station is the one which houses the new wind tunnel.

This tunnel is located in a building of brick and steel about 210 feet long and 100 feet wide. Plenty of windows and large skylights have been incorporated in the construction in order to have plenty of light. A large pit, about 8 feet deep, lined with cement, takes up the entire floor space of the building, with the exception of the gangways along the sides and ends. Next to this building is another one of similar construction, built to house the engines that will furnish the electrical energy to supply the tunnel.

The tunnel itself is of the Eiffel type and is entirely constructed of reinforced concrete. It was built in accordance with the design of the aerodynamic section of the French technical service and was constructed by the company of which Mr. Caquot, formerly of the technical section, is the head. The tunnel is supported by two huge concrete walls running longitudinally along the entire length of the tunnel. This leaves a free air space under the tunnel.

The entrance nozzle is set high up from the floor and back from the walls of the building. The section of the outer walls of the collectors has been made square instead of circular, and of a width equal in diameter to the front end of the collector. This permits the outer walls of the collector to be parallel to the walls and floor of the room and eliminates any break of contour caused by the experimental chamber. Aft of the experimental chamber the outer walls are gradually faired into the diffuser.

The diameter of the tunnel is 3 meters at the throat and 7 meters at the propeller end. It is to be driven by a six-bladed propeller. The section of each blade is to be exactly analogous to the arc of a circle. It will be possible to vary the pitch of the blades of the propeller, but this can not be done while it is in motion. The propeller will be driven direct by a 1,000-horsepower electric motor which will permit a speed of approximately 260 feet per second to be attained.

Behind the diffuser is a concrete stand for the motor. In order to change the direction of the air leaving the diffuser, the two forward faces of the stand are curved in the plane. It is proposed to continue these curves upward and outward by wooden partitions.

Entrance into the experimental chamber is gained by means of a passage with a staircase inside of one of the supporting walls of the tunnel. The passage is equipped with two steel doors to insure an air lock. The experimental chamber itself is very large, being roughly cubical, about 20 feet to a side. The diffuser ends and the collector project into the experimental chamber.

The only natural light in the chamber is that which comes through the collector.

The floor is equipped with a square trap closed by a movable platform. When it is desired to work with large models the movement of a lever lowers the platform sufficiently for it to come into contact with a track mounted on the inner faces of the two longitudinal walls below the tunnel. It can then be pushed back and out of the way and the large model admitted into the experimental chamber.

The tunnel is so designed that it can be partially or completely closed at the throat if desired.

A number of hooks have been imbedded in the concrete, flush with the surface of the diffuser and collector cones near the throat. These hooks can be pulled outward and to them the supports of smaller cones can be fastened. This will produce a tunnel 2.6 feet in diameter, concentrically placed within the larger tunnel. By using a small propeller and the power available for the large tunnel the French expect to obtain a speed of 1, 300 feet per second.

The method of suspending the model will be by wires instead of by a spindle as is generally practiced. It is understood that the balance will be of the dynametric type with various gauges to which the wires supporting the model will be attached.

The French hope that this tunnel will be used as standard and all other tunnels in France and, if possible, in the world, may receive correction factors based upon this particular tunnel in order to have a uniform system of measure for procuring aerodynamic information. This tunnel is unquestionably the most elaborate tunnel in existence to-day and very accurate results will probably be procured when it is put into operation.

The equipment at the St. Cyr Tunnel is very similar to that found in the laboratory of the National Advisory Committee of Aeronautics at Langley Field. However, they have several pieces of apparatus which are not used in this country, including a large whirling arm which can be used for propeller testing and procuring certain other information.

The most ingenious device installed, however, is a track for the testing of full-scale machines. A track about a mile in length has been built and carefully graded. The models are placed on a car equipped with facilities for measuring their aerodynamic balance at the various pressures. The car is supplied with electric power by a rail 16 inches above the ground on each side of the track. After allowing for acceleration and retardation, there is a useful run of about 1,650 feet, during which the readings are made showing the lift and drag values as well as the relative speed. The French claim to have procured some very interesting and useful data from experiments with this device.

WIBAULT DESIGN DRAFTING SYSTEM.

The Wibault Co. uses the system of designating their drawings which has been prevalent throughout France and England for several years. The idea is to simplify the number of drawings that are necessary to carry out the construction of experimental machines and to provide a simple means of designating drawings that will show their relation to the entire assembly.

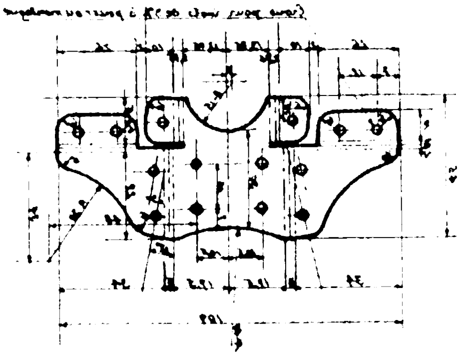
A single sheet contains a drawing on a reduced scale of the unit to be constructed with part numbers attached and

...bres de mesures N°s 3-4-5

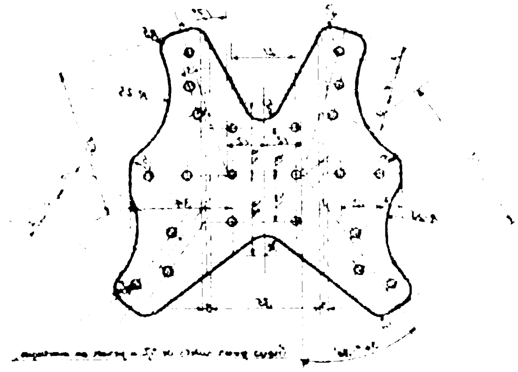
Plan N° 2203

Numéros		Désignation	Dimensions			Nature de la Matière
[illegible]		[illegible]		15/10		Aluminium
[illegible]		[illegible]		"		"
[illegible]		[illegible]		"		"
[illegible]		[illegible]		"		"
[illegible]		[illegible]		"		"
[illegible]		[illegible]		"		"
[illegible]		[illegible]		"		"
[illegible]		[illegible]		"		"
[illegible]		[illegible]		"		"
[illegible]		[illegible]		"		"
[illegible]		[illegible]		"		"
[illegible]		[illegible]		"		"

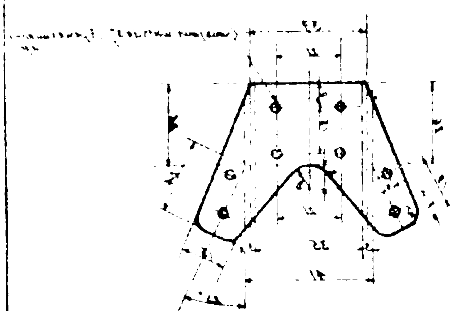
Pièce : N° 36022 (Aluminium 15/10)



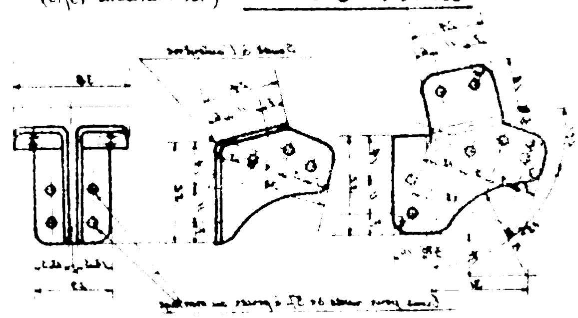
Pièce : N° 36019 (Aluminium-15/10)



Pièce : N° 36023 (Aluminium 15/10)



Pièce : N° 36020 (Aluminium-15/10)



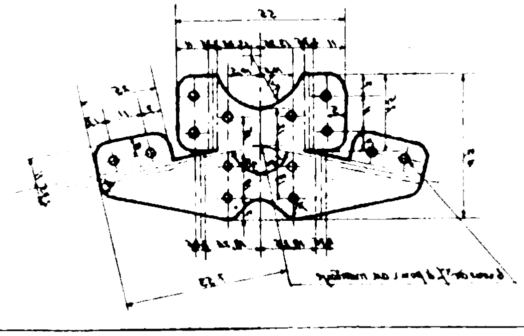
36.012
36.013
36.014
36.015
36.016
36.017
36.018
36.019
36.020
36.021
36.022
36.023

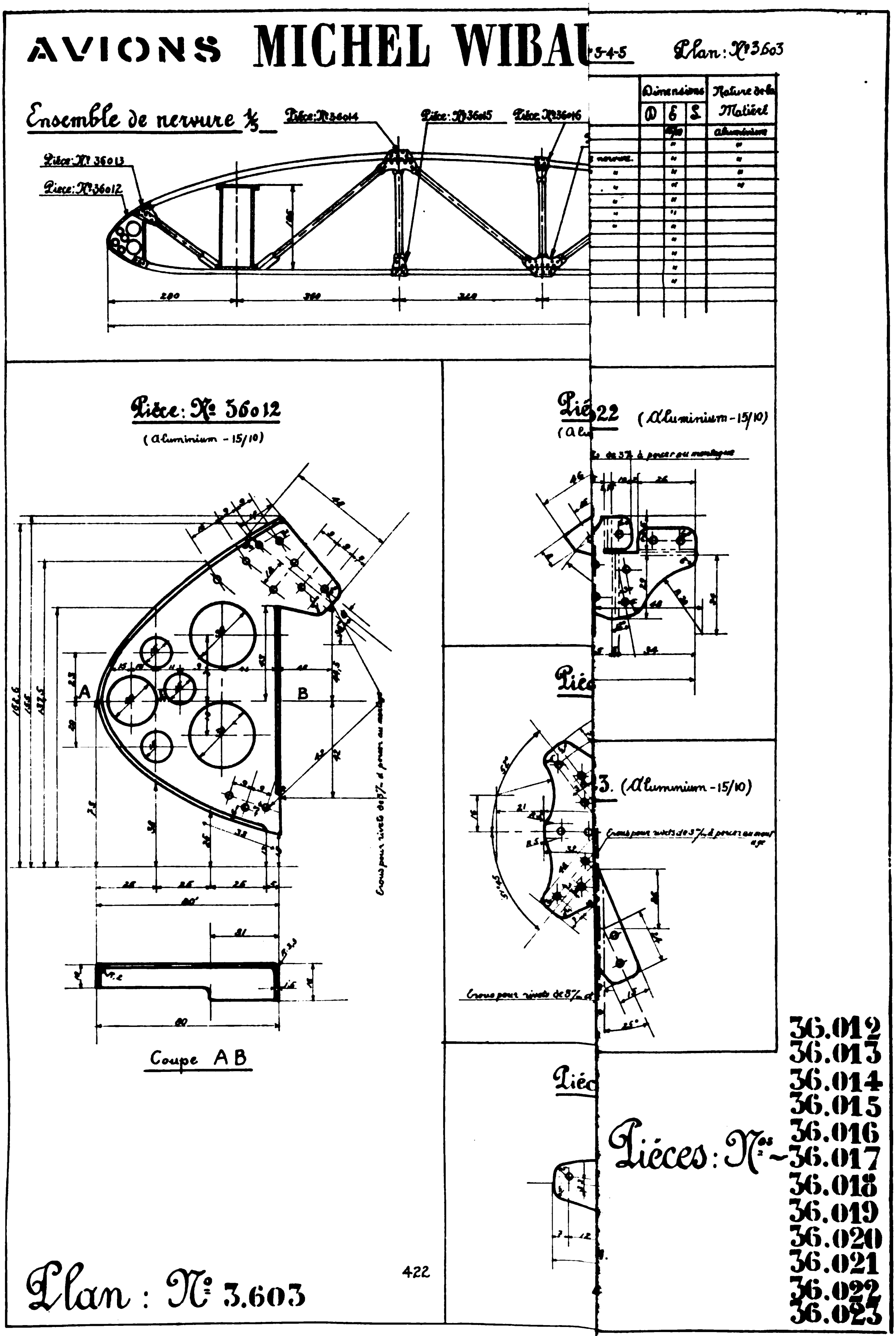
Pièces : N°s

Dessiné
Calqué
Vérifié

Paris le 19 Sept 1911

Pièce : N° 36021 (Aluminium-15/10)




AVIONS MICHEL WIBAU
Plan: Nº 3603
Ensemble de nervure 1/5
Pièce: Nº 36014
Pièce: Nº 36015
Pièce: Nº 36016
Pièce: Nº 36013
Pièce: Nº 36012
Dimensions
D E S
Nature de la Matière
aluminium
Pièce: Nº 36012
(Aluminium - 15/10)
A
B
Coupe AB
22 (Aluminium - 15/10)
3. (Aluminium - 15/10)
Pièces: Nºs
36.012
36.013
36.014
36.015
36.016
36.017
36.018
36.019
36.020
36.021
36.022
36.023
Plan: Nº 3.603
422

their frame rectangular outlines which are contained in numerical subdivisions of the sheet. These rectangular subdivisions contain detail drawings of specific parts. They are supposed to contain only the amount of information absolutely essential to carry out the experimental design. Figure 1 is a specimen of this type of design drawing which illustrates the principle involved. The first number on all design drawings and on all the detail drawings is explanatory of the type of aircraft to be constructed. For instance, in Figure 1 No. 3 C represents the third type of pursuit (chasse) by Mr. Wibault. Drawings Nos. 301 to 399 are the main assembly drawings which show, respectively, all the different installations. Other numbers are allocated to unit designs as follows:

Nos. 101 to 199 are numbers allotted for the fuselage drawings.

Nos. 201 to 299 are numbers allotted to the empennage, tail skid, and landing gear.

Nos. 301 to 399 represent the numbers that are allotted to armament and supercharger installations.

Each of these numbers is preceded by a three and a decimal point to indicate the ship to which the drawings pertain.

In addition to the hundred numbers allotted for the assembly drawings, 1,000 numbers are allotted for detail drawings. An example of this is in the assembly rib drawings, part No. 3603 (see fig. 1), which is understood to include in the assembly all the pieces as Nos. 36.012 to 36.023.

In the upper right-hand corner of the drawing is the nomenclature and gauge of the material and number required. In the lower left-hand corner is the number of the assembly. In the lower right-hand corner are the drawing numbers of the details illustrated on the sheet. All the nomenclature titles are of uniform type with respect to numeral, designation, spacing, and size, which facilities ease in identification and simplifies routing in the shop.

BLERIOT-SPAD-HERBEMONT AIRCRAFT.

The Bleriot-Spad-Herbemont Co. has been busily developing the following types since the war:

S-20. Mono-biplace pursuit; three machine guns; 300 horsepower; Hispano-Suiza. (August 7, 1918.)

S-15. Monoplace; touring; 80 horsepower; Le Rhone. (May 18, 1919.)

S-28. Monoplace; 300 horsepower; Hispano-Suiza. (September 26, 1919.)

S-27. Triplace (touring limousine); 275 horsepower; Hispano. (November, 1919.)

S-30. Monoplace touring; 45 horsepower; Anzani. (January, 1920.)

S-29. Biplace touring; 80 horsepower; Le Rhone. (January, 1920.)

S-38 bis. Biplace; 300 horsepower; Hispano. (February, 1920.)

S-26 and 26 bis. Speed and altitude hydroplanes; 275 horsepower; Hispano. (March, 1920.)

S-31. Hydroplane; 275 horsepower; Hispano. (April 10, 1920.)

S-32. Special altitude airplane; 200 horsepower; Damblanc Mutti. (June 10, 1920.)

S-33. Berline (8-place); 310 horsepower; Salmson, AZ-9.

S-33 bis. Berline (6-place); 275 horsepower; Salmson, Z-9.

S-34. Biplace; training, with double controls; 80 horse power; Le Rhone. (July 16, 1920.)

S-35. Mono-biplace pursuit; 180 horsepower; Hispano.

S-37. Four-place transport; 275 horsepower; Hispano. (September 9, 1920.)

S-20 bis. Monocoque special; Gordon-Bennett; 300 horsepower; Hispano. (September 22, 1920.)

S-20 bis. Monocoque; record speed (special profile); 320 horsepower; Hispano. (October 6, 1920.)

Of these types the most notable are the Spad 20, the Spad 20 bis, and the Spad 34 and 35.

SPAD 20 TWO-SEATER PURSUIT.

The Spad 20 is the 300-horsepower Hispano motored, two-place, and was designed in 1918 by Mr. Herbemont.

Characteristics:

- Motor, 300 horsepower Hispano; radiator, nose-type.
- Gasoline tanks: One under pilot's seat and two gravity tanks on the upper wings.
- Over-all length: 7.30 meters.
- Height: 2.8 meters.
- Wing span, upper: 9.72 meters.
- Wing span, lower: 8.69 meters.
- Chord, upper: 1.75 meters.
- Chord, lower: 1.65 meters.
- Gap, at center: 1.65 meters.
- Gap, at ends: 1.55 meters.
- Total area: 30 square meters.
- Weight, loaded, per square meter: 43.7 kilograms.
- Weight, per horsepower: 4.4 kilograms.
- Endurance, at 3,000 meters: 3 hours.
- Ceiling: 7,000 meters.
- Weight of wings, per square foot: 1 pound.

Performance:

- Speed at 2,000 meters: 270 kilometers per hou .
- Speed at 5,000 meters: 210 kilometers per hour.
- Climb to 2,000 meters: 6.6 minutes.
- Climb to 3,000 meters: 10.7 minutes.
- Climb to 5,000 meters: 25.65 minutes.
- Minimum flying speed: 107 kilometers per hour.
- Weight, empty: 1,863 pounds.
- Useful load: 1,010 pounds.
- Total weight: 2,873 pounds.
- Gasoline: 335 pounds.
- Oil: 37 pounds.
- Equipment: 352 pounds.
- Armament: 205 pounds.
- Miscellaneous: 35 pounds.
- Tank protection: 54 pounds.

This machine represents the best performing two-place job that the French have in their air service. It has been built in numbers and is being used to quite an extent along the French-German frontier. The mounting of the Hispano motor is unique from the standpoint of its rigidity and the effectiveness with which the vibration is absorbed. It is very inaccessible, however, and the motor must be pulled from the front of the fuselage in order to get it out of the machine. The only accessibility is derived from two removable pieces of cowling on each side of the fuselage.

The top longerons extend directly over the motor. To them the center section struts are fastened. The fuselage is built of the famous Spad monocoque construction. Mr. Herbemont claims that the advantages of the monocoque construction are as follows:

1. Absolute freedom from deformation even after long service and numerous landings.
2. Extreme lightness.
3. Simplicity of construction, reduction in the number of materials, and economy in repair.
4. Absolute interchangeability of monocoques.
5. Reduction in head resistance.
6. Facility in dismounting motor. No derangement of the fuselage occurs and the motor can be quickly removed.
7. Accessibility to all parts of motor.
8. Construction affords pilot almost complete visibility and reduces to a minimum parasite resistance.

Of course, it will be inferred that these claims are questionable in many respects. This type of construction would be best where dynamic interpretation of outline would be an advantage and where extreme climatic changes are not prevalent.

However, this machine, with the Nieuport 29, represent the finest streamline pursuit jobs in Europe. This machine has been interpreted in another type, a single-seater pursuit, with two machine guns and having a total load of 358 kilograms. The ground speed of this type was 236 kilometers per hour.

Climb to 5,000 meters: 17 minutes 45 seconds.
Climb to 6,000 meters: 26 minutes.

SPAD HERBEMONT RACING TYPE.

This is a modified Spad Herbemont S-20 with a different wing structure and with the further adaptation of cleanliness in exposed detail design with the object of diminishing resistance. The wing area in this type is 14 square meters.

Total weight: 1,050 kilograms.
Weight of load: 200 kilograms.
Motor: 320-horsepower Hispano.
Load per horsepower: 3.28 kilograms.
Load per square meter: 76 kilograms.

This machine has realized 309 kilometers per hour over a 4-kilometer course.

BLERIOT COMMERCIAL AIRPLANE, SPAD TYPE 45.

General characteristics:

Biplane with two tractor screws and two pushers.
Four 275-horsepower naval type Hispano-Suiza engines.
Span: 70.5 feet.
Length: 50.2 feet.
Height: 19 feet.
Wing area: 1,560 square feet.
Weight, empty: 7,700 pounds.
Fuel load: 3,080 pounds.
Passengers, luggage, etc.: 4,620 pounds.
Total weight: 15,400 pounds.
Load per square foot: 9¼ pounds.
Load per horsepower: 14 pounds.
Speed: 124 miles per hour.
Endurance at full power: 5 hours.

The Spad 45 is a transport airplane, with four 275-horsepower Hispano-Suiza engines, designed to carry 17 passengers and a crew of 3.

In the nose of the fuselage is the station of the navigator with the wireless telegraph, signal, and navigation instruments. Aft of the navigator and forward of the wings are two pilots placed side by side and having good visibility. Behind the pilots and at the center of gravity, between the planes of rotation of the forward and aft propellers, a large cabin is arranged for 15 persons. Under the floor of this cabin there is a large luggage hold containing a mechanic's seat. While the machine is in flight the mechanic can visit the two engine nacelles to make small repairs. Aft of the main cabin there is a lavatory and a double seat permitting two passengers to travel in the open air.

The central part of the cellule has forward stagger, the swept-back upper plane being 3.3 feet forward of the lower plane at the center. The lower plane is in three parts with a straight leading edge. Two symmetrical ailerons, controlled by a lever and crank arrangement, are placed at the outer rear corners of the lower plane.

The two planes, 10.6 feet apart, are connected by two struts (one on each side of the fuselage). To reduce head resistance, the bracing wire terminals are in the thickness of the wings.

The monocoque fuselage is composed of two layers of strips of tulip wood, 20 millimeters in thickness, and and one layer of spruce, 40 millimeters thick, covered with fabric on the outside.

The landing gear is composed of two vees of several thicknesses of hardwood and covered with fabric. These vees are connected at their lower end by two steel tubes between which lies the divided axle. There are two wheels arranged in tandem attached to each end of the axle by a special mounting permitting the contact of all four wheels with the earth regardless of the irregularities of the terrain. A strut runs from each side of the landing gear to the lower wing directly under each engine nacelle. The wheels are 1,000 by 180 millimeters (3.28 by 0.59 foot). Streamline wire cross bracing assures the rigidity of the structure.

The ash skid attached to the rear of the fuselage is in two parts, an upper fixed portion and a lower pivoted portion. The latter has a rubber shock absorber and a steel skid.

The rudder and elevator are connected to the controls by steel cables in duplicate.

The stabilizer and fin are adjustable in flight.

The four engines are arranged in two groups of two in tandem and are placed on the lower plane on each side of the fuselage.

The engine nacelles are easily removable and thus permit the use of any engine, and the nacelles are interchangeable. Repairs are very easy and are made at the workshop on complete nacelles removed from the airplane. In case of engine failure, the entire engine nacelle may be changed in a few minutes by removing a few bolts.

NEW PURSUIT SHIP.

The Spad Co. has designed and are building a single-seater, 300-horsepower Hispano motor, monocoque, high-altitude machine, supercharged with a Rateau super-

charger. It is impossible to get any characteristic data on this machine, but we saw the fuselage and landing gear for this type in the Bleriot factory under construction. The fuselage is smaller in cross-sectional arrangement than the Spad 30 and is much shorter. There is no doubt but that this machine with the superchargers ought to have a very superior performance as a high-altitude single-seater. It is of the conventional Herbemont biplane, single-strut type with bottom wing ailerons.

The trials of this machine ought to be followed very closely as soon as developments have warranted its test flights. Supercharger installation is very neatly carried out and is mounted in such fashion as not to add excessive head resistance or obstruction of vision. A semicircular copper air leader is located just below the fuselage in back of the propeller.

NEW OBSERVATION MACHINE.

A two-seater Herbemont observation type is also being built with superchargers. The motor mounting, however, is different from the conventional type, inasmuch as it is of cantilever steel tube type. It is in a monocoque fuselage, thus rendering an accessible motor installation possible with all the advantages of monocoque streamline construction. This machine represents one of the latest departures in two-seater, supercharged observation type development and its trials and performances should be closely watched. The performance of this machine should be compared to the Breguet Sesquiplan. It is noteworthy that on most of the latest Herbemont machines, Lamblin water-cooling systems are in vogue.

SPAD, MARINE TYPE.

Another Spad machine has been undergoing trials and one model which was in the Bleriot shops for improvements was the Spad 20, remodeled as a marine type.

The principal characteristics of this machine are:

Span: 10.47 meters.
Length: 7.90 meters.
Total weight: 1,488 kilograms.
Weight per horsepower: 5.4 kilograms.
Area: 33 square meters.
Weight, empty, with water: 1,028 kilograms.
Weight per square meter: 45 kilograms.

The principal departure of this machine from the conventional type was the adoption of a landing gear pontoon with streamline section in place of the conventional hydrovane that is customarily used on machines of this type.

This machine is approximately 100 kilograms heavier than the land type and with about 10 kilometers less speed.

The French marine service demands characteristics of performance as follows:

Climb to 2,000 meters: 15 minutes.
Useful load: 470 kilograms.
High speed: 200 kilometers per hour.

This machine climbed to 2,000 meters in 14 minutes and made a high speed of 211 kilometers per hour. It was a very remarkable performance for this type of machine, considering the added chassis resistance. It closely resembles the regular Spad Herbemont 20 job.

SPAD HERBEMONT S-34—DUAL CONTROL.

This machine has been designed as a side by side training plane. The fuselage of this machine is not built of the characteristic Herbemont monocoque construction, but of the regular stick and wire construction. It is rectangular in shape.

Characteristics are as follows:

Total area: 20 square meters.
Length, over all: 6.40 meters.
Span: 8.15 meters.
Height: 2.36 meters.
Weight, empty: 370 kilograms.
Total load: 590 kilograms.
Motor, Le Rhone: 80 horsepower.
Speed near ground: 145 kilometers per hour.

This is a very interesting training type and the visibility for both pilot and student is very well worked out in this design. The job on a whole is a very good manufacturing proposition and is equally well designed for maintenance in the field. It is of the single-strut, single-bay type. The disposition of instruments and controls in the common cockpit is ingeniously carried out. Several of the French pilots seem to be very much in favor of this type of machine for training purposes.

SPAD BERLINE TRANSPORT, TYPE S-33.

This machine has been designed to carry seven passengers. It has a very comfortably designed cabin arrangement for the passengers. Its fuel capacity is 6 hours at 190 kilometers per hour. The passengers' cabin is placed directly over the center of gravity of the machine, behind the motor and in front of the pilot. This tends to offset the rolling characteristic so often found in airplanes with a load situated far back. It also permits the machine to fly with only a percentage of the total number of passengers without throwing the machine out of balance and without making it necessary to modify the tail setting. The passengers all sit in the machine facing toward the front. The entering door to the cabin is located near the front. This job is geometrically similar to the Spad 20 and is of monocoque construction.

Characteristics of this machine are as follows:

Tractor biplace motor, Salmson AZ 9: 310 horsepower.
Weight, empty: 1,000 kilograms.
Total weight: 1,900 kilograms.
Span: 11.664 meters.
Length: 9.88 meters.
Height: 3.2 meters.

THE NIEUPORT AIRPLANES.

The Nieuport Co. is one of the most important aeronautical combinations in France. They are building a great number of machines and earning enough to carry out an active development program. This concern built large numbers of machines during the war, especially of the XXVII and XXIII types.

As stated in the résumé, they are still confining themselves to the stick-and-wire construction with their characteristic monocoque fuselage.

NIEUPORT XXIX C-1.

The Nieuport XXIX C-1 is the famous standard pursuit plane of the French air force and unquestionably is a masterpiece. It has been especially designed for combat work under conditions found in France and has a wonderful combination of the best qualities of speed, climb, and maneuverability.

The characteristics are as follows:

Length: 6.5 meters.
Span: 9.7 meters.
Area: 27 square meters.
Motor: 300 horsepower Hispano.
Weight, empty: 761 kilograms.
Fuel weight: 172 kilograms.
Useful load: 167 kilograms.
Total weight: 1,100 kilograms.
Endurance: 2 hours.

The performance is as follows:

Speed at ground: 266 kilometers per hour.
Climb to 6,000 meters: 18 minutes 46 seconds.
Ceiling: 8,500 meters.

This machine is of the monocoque construction, of the type first evidenced in the Nieuport XXVIII monoplace. It represents, for its load, the best performing single-seater in France. It is featured primarily by its fuselage outline of superior aerodynamic qualities to any other European machine.

The method of construction of the monocoque is of primary interest, inasmuch as this type of construction, even though it is of wood with the ordinary advantages and disadvantages of wooden construction, permits the realization of the best shape. The shell is built entirely in one integral unit on a longitudinally collapsible wooden form. The diameter of the fuselage is approximately 32 inches at the master section. The fuselage sections proper throughout all transverse sectional stations from nose to stern are circular in section. This facilitates the construction of the fuselage form to a marked degree. The form can be withdrawn in conic sections from the front of the fuselage. The shell is constructed of plies of tulip wood approximately 1 millimeter thick and from 1 to 2 inches wide, wrapped in transverse, biased fashion around the form. The form is first covered with light-weight brown paper to prevent adhesion of the glue from the shell layers to the form itself.

Centrally located in an axial sense is a mandrel to which fuselage-form sections are fastened. It is supported at its extremities on V-shaped borings mounted on wooden floor horses. This convenience facilitates rotation of form throughout range of 360° to enable the women workers to completely wrap fuselage in single cycle operation. Five hundred and fifty women-hours are required to make a complete Nieuport fuselage shell, exclusive of interior trusswork for cockpit and motor compartment sections. The trusswork aft, which consists of 10 triangular longitudinals and annular ring veneer ribs, is assembled on the form before the shell is built around it.

The stabilizer, as well as the top and bottom fin, is built in monocoque fashion integral with the fuselage. The elevators and rudder are of conventional construction. The tail unit is devoid of any external bracing. The wings are of the combination two-bay truss type with counter-balanced ailerons on the bottom wing only.

The cooling system uses Lamblin radiators which allow a better streamline fuselage form with proper entry shape which is so hard to procure with the conventional type with nose radiators or ordinary radiators in free-air position in close proximity to the fuselage. The bad effects of radiator interference are reduced to the minimum. The Lamblin radiators are mounted in a free-air position in the region of maximum air velocity. They are placed in the two vees of the undercarriage and the deflection of air flow from its natural course of both radiator and fuselage is practically nil.

This machine has exposed gun mounts and a detachable gasoline tank immediately forward of the pilot, between him and the engine. The oil tank is situated directly under the motor and has a Lamblin-type oil radiator. This machine has further been made into a high-altitude type with a Rateau supercharger. Two hundred of these machines are now being constructed by the Nieuport Co. for the French Army air service.

NIEUPORT DELAGE SESQUIPLAN.

This machine is the famous Nieuport racer. The general characteristics are as follows:

Total length: 6.1 meters.
Height: 2 meters.
Span: 8 meters.
Chord: 1.5 meters.
Area total wing: 10 square meters.
Area landing gear plane: 1 square meter.
Total area including 1.4 square meters for ailerons: 11 square meters.
Stabilizer: 1.28 square meters.
Elevator: 0.72 square meter.
Vertical stabilizer: 0.56 square meter.
Rudder: 0.44 square meter.
Weight, empty: 700 kilograms.
Pilot: 86 kilograms.
Weight of fuel for flight of 10 minutes 46 seconds: 144 kilograms.
Total weight: 930 kilograms.
Load power per square meter: 84.5 kilograms.
Load power per horsepower: 2.9 kilograms.
Motor, Hispano-Suiza, 140 by 150, giving at 1,900: 320 horsepower.
Propeller diameter: 2.3 meters.
Pitch: 3 meters.
Radiators: Lamblin.
Oil coolers: Lamblin.
Fuselage: Monocoque.
Dihedral: 1.3°.

The wing is formed of two spruce spars, braced by compression tubes of steel in the lift truss terminating in the landing gear with crosstie pieces of steel. The surface is veneered and the entering edge of the wing is veneered.

This machine has attained a speed of 206 miles per hour and represents the fastest machine in the world to-day.

NIEUPORT TYPE XXXII SINGLE-SEATER SHIP PLANE.

This machine is specially designed for shipboard use. It is armed with two machine guns and can be utilized for marine pursuit and reconnaissance missions. It is practically the same as the Nieuport XXIX in outline and construction, as will be noticed from its outline

characteristics. Its low-loading and general flying characteristics tend to make it a very good interpretation of a shipboard pursuit and reconnaissance plane.

Characteristics:

Length: 6.7 meters.
Span: 9.7 meters.
Area: 30 square meters.
Motor: 180 horsepower Le Rhone.
Weight, empty: 603 kilograms.
Fuel weight: 174 kilograms.
Useful load: 80 kilograms.
Total weight: 857 kilograms.
Flight endurance: 4½ hours.

Performance:

Speed at ground: 193 kilometers per hour.
Climb to 3,000 meters: 12 minutes 3 seconds.
Climb to 5,000 meters: 24 minutes.
Climb to 6,000 meters: 38 minutes 29 seconds.

It is unnecessary to describe the other Nieuport machines, as they are well known, and data concerning them is available in our technical files.

BREGUET AIRCRAFT.

SESQUIPLAN 19 A 2.

The Breguet plant is located at Villacoblay. The most notable new type under construction is the Breguet Sesquiplan 19 A 2, which is a military corps d'armée and grande reconnaissance type. This machine has been specially studied to combine characteristics of speed and climb with effective armament, modern wireless installation, heat for the pilot, lighting and photographic installations, to a degree that would make this airplane perfectly adapted to the requirements of a modern war.

General characteristics:

(a) Sesquiplan with semithick wings.
(b) Tractor propeller, 2-place dual control.
(c) Motor, Renault: 450 horsepower.
(d) Span, upper wing: 14.85 meters.
(e) Span, lower wing: 9.54 meters.
(f) Length: 9.2 meters.
(g) Height: 3.3 meters.
(h) Total surface: 45 square meters.
(i) Chord: 1.9 meters.
(j) Wheels: 800 by 150.
(k) Gasoline: 450 liters.
(l) Oil: 28 liters.
(m) Weight, empty: 1,155 kilograms.

Military part.—

(a) Military load totals 750 kilograms, made up of equipment, gasoline for four (4) hours full out at sea level, armament, wireless, heating arrangements, lighting and photographic installations.
(b) Weight empty: 1,155 kilograms.
(c) Load: 750 kilograms.
(d) Total weight: 1,905 kilograms.
(e) Rate of climb:

1,000 meters: 2 minutes 45 seconds.
2,000 meters: 5 minutes.
3,000 meters: 7 minutes 45 seconds.
4,000 meters: 11 minutes.
5,000 meters: 15 minutes.
6,000 meters: 22 minutes 30 seconds.
7,000 meters: 40 minutes.

Military part—Continued.

(f) Horizontal speed:

Ground: 230 kilometers.
1,000 meters: 227 kilometers.
2,000 meters: 224 kilometers.
3,000 meters: 220 kilometers.
4,000 meters: 215 kilometers.
5,000 meters: 210 kilometers.
6,000 meters: 204 kilometers.
7,000 meters: 196 kilometers.

(g) Absolute ceiling: 7,900 meters.
(h) Service ceiling: 7,400 meters.

Description of installations.—(a) Electrical installation: The various supports, boxings, and fittings necessary to receive the electrical installation in detail are provided in this design as well as generator and storage battery installations. Provisions for wiring throughout the fuselage and wings, switches, boxes, fittings, and supports necessary for the wireless receiving and sending set, signaling outfit, heated clothing, cockpit lighting and lights are provided.

(b) Photographic accessories: The installation provides for a vertical photographic outfit of 0.50 to 1.20 meter focal length. For oblique photographic purposes, a 0.50 meter focal length. Installation of plate holders and fuselage floor sight glass is also made.

(c) Armament: (1) Installation for one (1) fixed synchronized Vickers or Darne machine gun in front cockpit.

(2) Synchronizing apparatus regulating fire of this machine gun.

(3) Bowden trigger control controlling fire of this fixed machine gun.

(4) Tourelle mount pivoted, 800 millimeters in diameter, capable of receiving two (2) Lewis or Darne machine guns, actuated by the observer or gunner in rear cockpit.

(5) Installation of a Chretien sight.

(6) Ammunition boxes for the fixed machine gun and magazine cartridge trays for the tourelle mount.

(d) Fuel system: (1) One A. M. sylphon gasoline pump, actuated by the motor, supplies the gasoline to the carburetor under constant pressure.

(2) One upper tank — 230 liters capacity — with Lanser protection rendering it inexplosible and noninflammable.

(3) Lower tank—220 liters capacity—which could be detached at will by the pilot.

(4) In the pilot's cockpit are the following instruments:

One radiator water thermometer.
One motor tachometer.
One gasoline capacity gauge for each gas tank.
One cockpit elevator control compensator.
One cockpit rudder control compensator.
One speed indicator.

General description.—This machine is of the single-bay, single-strut type, without wires in the plane of the lift truss, but with landing wires extending from the top longerons to the bottom wing at outer strut point. The fuselage is of the conventional Breguet type, duralumin tubing and steel fitting construction and with sides fared with crowning from top to bottom. The radiator is of the annular fin type, located just back of the propeller, the elements being quite similar to the famous Lamblin type. The landing gear is of the conventional Breguet type with wires extending from the rear of the landing gear to the bottom wing at the outer strut point to complete the rigidity of the wing cellule lift truss. The tail surfaces

are of the conventional Breguet type. Ailerons are fitted to the bottom of the top wing only. The propeller is fitted with a spinner.

Comments.—This machine is very interesting from a standpoint of cleanliness and design, coupled with the realization in a large degree of the requirements laid down by the French service for such a type. The Breguet type of metal construction, especially the fuselage, is such as to allow great accessibility. The visibility is quite good. The elevators and rudder are counterbalanced but the ailerons are not. This machine is one of the two best interpretations of metal construction that was seen in France. The Breguet engineers fully realize the great value of streamlining. They attribute much of the high speed and climb characteristics to streamlining.

BREGUET LEVIATHAN TRANSPORT, TYPE XXII, 900 HORSEPOWER.

This machine is motored with two 450-horsepower Breguet Bugatti motors. The motors are located between the wings and out from the fuselage. The characteristics of the machine are as follows:

(a) Span: 25.5 meters.
(b) Length: 14 meters.
(c) Height: 5 meters.
(d) Total surface: 140 square meters.
(e) Weight, empty: 3,000 kilograms.
(f) Useful load: 3,500 kilograms.
(g) Weight per square meter: 40 kilograms.
(h) Weight per horsepower: 7 kilograms.

This machine has been especially studied for commercial purposes, although it could be changed into a military model, if necessary.

Nature of load for a radius of 600 kilometers:

(a) Two pilots: 150 kilograms.
(b) Wireless: 100 kilograms.
(c) Gasoline, 940 liters: 675 kilograms.
(d) Oil, 83 liters: 75 kilograms.
(e) Twenty-five passengers with baggage: 2.500 kilograms.
(f) Total useful load: 3,500 kilograms.
(g) Total weight of machine loaded: 6,500 kilograms.
(h) Speed at 2.000 meters: 170 kilometers.
(i) Endurance of flight: 3½ hours.
(j) Service ceiling: 4,000 meters.

Nature of load for a radius of action of 1,100 kilometers:

(a) Two men: 150 kilograms.
(b) Instruments and radio: 100 kilograms.
(c) Gasoline: 180 kilograms.
(d) Oil: 120 kilograms.
(e) Twenty passengers and baggage: 2,050 kilograms.

The pilot is placed immediately behind the main passenger cabin. He has excellent visibility for all flight conditions and also can see the ground for landing purposes. In close proximity to the pilot is an aide pilot-navigator, who also operates the wireless, which is installed in the cabin in immediate proximity. Doors permit the passage from the pilot's cockpit to the passenger's cabin or to the radio cabin.

Arrangement of cabin.—A door placed in the front of the fuselage permits ease of mounting into the passenger's cabin. A stepladder is carried on board for mounting and dismounting. The cabin is about 7 feet high and spacious and comfortable. The visibility is excellent and the ventilation of the cabin is automatically regulated to any degree for the passengers' comfort. A passage running to the rear of this cabin permits the passengers to have access to a lavatory. Space is provided for the passengers' hand baggage.

Power plant.—The motors are two groups of Breguet Bugatti bimotor 450 horsepower.

Summary.—The construction of the wings and fuselage is entirely of duralumin. Their construction is too complicated to adopt for military or commercial craft. This machine represents an experiment in the fine art of handling duralumin for aircraft construction. The rings are very light in weight (about 1 pound per square foot) and the construction emphasizes the comparative advantages of metal construction over wood where weight is concerned. This construction would be impossible in production.

The machine had never been flown to date and at the time we were in Paris the first machine was being sand tested. The machine is very conventional in outline, of the twin-motored central fuselage type, with the wide track landing near with double wheels. Each wheel is 52 inches in diameter, equipped with the latest Palmer flat-tread tires.

BREGUET COMMERCIAL SINGLE MOTOR TRANSPORT MACHINE.

This machine is powered with a 300 horsepower Renault and is practically the same as the Breguet ambulance airplane (described below). The stretcher equipment has been removed and comfortable seats provided for the passengers. Further data and photographs of these machines were procured and will be found in our files.

SUPERCHARGERS, OBSERVATION, AND CORPS D'ARMÉE.

Breguet is also delivering a quantity of duralumin all-metal tubing jobs for high-altitude observation work. They have a 450-horsepower Renault with a Rateau supercharger. The air cooling for the supercharger is taken care of by two air radiators on the side of the fuselage. Lamblin radiators are used for water cooling. The Breguet Co. have tried metal covering on some of their experimental ships and have used a system which is quite novel. Sheets are rolled very thin and are cut into strips about 1½ inches wide. Both edges of the strips are bent back and the strips are riveted together by fastening these flanges. The smooth side of the covering is external and although it is a very nice job to look at, it is not very practical on account of the number of labor hours required and the fact that the covering is so thin that the vibration would crack it. Some pontoons in the factory have been built up in the same way, but were found to be unsatisfactory. Breguet type duralumin tubing and steel fitting fuselage construction is most interesting from the standpoint of practicability, and of structure with low-weight and high-strength factors.

BREGUET TYPE XIV.—DAY BOMBARDMENT.

This machine has been very fully described in data which we have in our technical section and is of the conventional Breguet type construction throughout.

One of the interesting features of the night bombardment type is the arrangement of the bomb-sight apparatus

situated on the right side of the observer's cockpit. A hole is cut in the fuselage fabric covering midway between the top and bottom longerons on the right side of the gunner observer's cockpit. A blinker or air deflector is located ahead of this hole so as to deflect the slipstream which would otherwise interfere with sighting. The bomber sits near the bottom of the fuselage and sticks his head out through this hole to do his sighting. The bomb sight is immediately back of this blinker door and protected from the slipstream. The door is operated at will, usually, by the bomber. The vision is good and accuracy has been attained by this method. The seat for the bomber must be provided in two locations. One permits his operating the dual control or going along in regular flight in observation work and the other permits him to bomb or take pictures.

BREGUET AMBULANCE PLANE—XIV T.

This machine is one of the standard Breguet types, powered with the 300-horsepower Renault, designed to carry two patients, one above the other and ahead of the pilot, who occupies the position that the gunner or observer does in the ordinary military types.

It is a very interesting adaptation of a military machine for ambulance purposes and at best represents more or less of a makeshift of their regular jobs to suit the purpose.

On the right side of this machine is a door permitting the attendant to accompany the two patients and sit alongside of them. A cabinet placed in immediate proximity contains a complete first-aid equipment and different-sized syringes, thermos bottles, morphine, caffeine, ether, sparteino, camphor oil, serum, scissors, nickel-plated cleaning utensils, bandages, disinfectants, etc. A small table permits the disposition of this material by the physician accompanying the patients to soothe the immediate needs of the injured. A complete electrical installation permits lighting the compartment and heating the blankets in the patients' litters. This energy is furnished by a propeller-driven generator.

A French service report is filed in our technical data files showing the service to which these Breguet ambulance jobs have been placed in Morocco in 1921. It is convincing evidence of the importance of ambulance jobs for field work in dangerous first-aid cases demanding immediate, skilled medical attention.

BREGUET SHORT DISTANCE NIGHT BOMBARDMENT, TYPE XVI.

Characteristics:
- (a) Biplane, tractor, dual control.
- (b) Motor, Renault: 450 horsepower.
- (c) Span, upper wing: 17 meters.
- (d) Span, lower wing: 17 meters.
- (e) Ailerons counterbalanced.
- (f) Total length: 9.55 meters.
- (g) Height: 3.32 meters.
- (h) Total surface: 73 square meters.
- (i) Gasoline capacity: 430 liters.
- (j) Flight endurance: 5½ hours.
- (k) Total weight: 2,450 kilograms.

14799—23——3

PERFORMANCE WITH 300-HORSEPOWER RENAULT.

(a) Military load: 1,130 kilograms, of which 550 kilograms were bombs.
(b) Climb:
- 1,000 meters: 10 minutes 35 seconds.
- 2,000 meters: 21 minutes 54 seconds.
- 3,000 meters: 37 minutes 43 seconds.
- 3,500 meters: 51 minutes 10 seconds.

(c) Ceiling: 4,600 meters.
(d) Maximum speed, ground: 160 kilometers per hour.
Maximum speed, 2,000 meters: 150 kilometers per hour.
Maximum speed, 3,000 meters: 139 kilometers per hour.
Maximum speed, 4,000 meters: 138 kilometers per hour.

This machine is equipped with two Michelin bomb racks, located underneath the wings, which permits various combinations up to a load of 550 kilograms. Total weight in bombs of different sizes as follows:

Number of bombs.	Weight of each.	Diameter.	Total weight.
	Kilograms.	*Millimeters.*	*Kilograms.*
32	10	90	320
32 (incendiary)	10	120	320
16	25	155	400
8	50	200	400
5	100	275	500
2	200	380	600
2	100	275	

The bomb-rack fittings are so designed as to carry two bomb flares of the Michelin type, weighing about 11 kilograms each. The bomb-dropping control mechanism is of the Michelin type. The gasoline system of the A. M. Sylphon pump type, motor-driven. The gasoline tank is of 430 liters capacity in two compartments with Lanser protection.

Summary.—This machine has been built with different engine installations. A Liberty motor has been used. This is a machine of unique characteristics with a reliable power plant, capable of carrying a large load. It is the best performance that has been obtained with a 300 Renault. Its characteristics are such that the French air service has placed large orders for it in the past and have many on order at present.

BREGUET TWO-SEATER FIGHTER, TYPE XVII.

Characteristics:
- (a) Biplane, tractor, 2-place, dual control.
- (b) Motor, Renault: 450 horsepower.
- (c) Span, upper wing: 14.200 meters.
- (d) Span, lower wing: 12.560 meters.
- (e) Upper ailerons only counterbalanced.
- (f) Height: 3.460 meters.
- (g) Length: 8.1 meters.
- (h) Area: 45.3 square meters.
- (i) Gasoline: 450 liters.
- (j) Endurance: 4½ hours.
- (k) Total weight: 1,840 kilograms.

Performance.—The following performances have been officially obtained with a military load of 625 kilograms.

(a) Climb:

2,000 meters: 5 minutes 45 seconds.
3,000 meters: 9 minutes 30 seconds.
4,000 meters: 14 minutes.
5,000 meters: 20 minutes 41 seconds.
6,000 meters: 31 minutes.

(b) Ceiling: 7,500 meters.

(c) Maximum horizontal speed:

Ground: 221 kilometers per hour.
2,000 meters: 218 kilometers per hour.
3,000 meters: 213 kilometers per hour.
4,000 meters: 207 kilometers per hour.
5,000 meters: 199 kilometers per hour.
6,000 meters: 186 kilometers per hour.

Armament.—The armament installation consists of two fixed Vickers machine guns, synchronized, one Aldis sight, two tourelle mounted Lewis machine guns, and provision for one floor gun if necessary. This machine is of a well-known type and of the conventional Breguet type of construction. It is very similar to the Breguet machines that we have on hand in this country.

Provision is made for electrical installation, oxygen installation, water thermometer, tachometer and speed indicators.

The gasoline system is of the A. M. Sylphon motor-driven type. The upper gasoline tank, Lanser protected, is of 230 liters capacity, and the lower tank of 220 liters capacity is detachable.

POTEZ MACHINES.

The Potez Co. is doing considerable work with metal construction and have designed and built two types of machines to French military specifications as well as several machines for commercial work.

Their two-place observation and night pursuit machine has the following characteristics:

Span: 12 meters.
Length: 8.40 meters.
Area: 45 square meters.
Motor: Lorraine, 370 horsepower.
Weight, empty: 1,100 kilograms.
Fuel: 255 kilograms.
Military load: 400 kilograms.
Total weight: 1,725 kilograms.
Loading per square meter: 39 kilograms.
Loading per horsepower: 4½ kilograms.
Speed at ground: 210 kilometers per hour.
Speed at 3,000 meters: 195 kilometers per hour.
Speed at 5,000 meters: 180 kilometers per hour.
Climb to 1,000 meters: 3 minutes 30 seconds.
Climb to 3,000 meters: 13 minutes.
Climb to 5,000 meters: 29 minutes.
Ceiling: 6,200 meters.

This machine has been designed to fulfill French type requirements for observation and night pursuit. This machine is representative of conventional type in design and is featured with Lamblin radiator installation. It is apparently a good all-round, strong machine with no particular features of construction, and the type is very closely analagous in seating arrangement and general layout to our DH-4B.

The Potez Co. is now experimenting and building up this machine of duralumin shapes. The fuselage longerons are being made of duralumin angles with gusset plate strut longeron joints, braced transversely by means of duralumin gussets only, and fore and aft with wires.

Their new duralumin wing construction is quire simple. It is a new interpretation of metal construction, being entirely built up of duralumin channels, angles, and gusset plates throughout. It is very easy to manufacture. It will be interesting to watch the development of this machine in metal.

Another interesting ship is the three-motored colonial type, designed to carry 10 or 12 passengers. This machine has folding back wings. It has a total wing area of 94 square meters and a weight of 3,500 kilograms. The wings, longerons, ribs, etc., are entirely of duralumin. The longerons in this job are of a T profile section, made from two pieces riveted together. The wire gusset fittings entirely envelop the longeron and in this manner detract from the fatigue and strain that would be the case with wire attachment bolts directly piercing longerons. The ribs are built up of U sections with trelliswork type truss. These ribs have withstood a static test of 10 load factors.

The landing gears are very unique, made up of three separate twin-wheeled chassis. Each one of these chassis has two rear legs working in telescopic fashion. The compression induced in the telescopic action is resisted by a shock absorber made of rubber washers. These washers are absolutely distinct and separated from one another by metal washers so as to prevent fraying between them. This landing gear has withstood a load of 15,000 kilograms without any permanent deformation. The striking advantage of using these rubber washers is the fact that the shock-absorbing medium is absolutely separate and apart throughout the telescopic barrel. Thus it does away with a possibility of serious damage to the machine due to the breakdown of the shock absorbers, such as occur with present types. These shock-absorbing legs can be very readily replaced in the field. The exterior is clean, easy to streamline, and allows the axle and the wheels to be mounted in a unit.

Another unique feature of the Potez three-motor job is the adjustable vertical tail surface and horizontal surface. There are three vertical fins, one fixed and two movable. The two movable fins are counterbalanced single surface and actuated by a cockpit handwheel with a worm-actuating mechanism. Apart from the fixed stabilizer is a movable, counterbalanced stabilizer which is likewise operated and controlled for variance of incidence from the cockpit.

This machine is well thought out and is a good interpretation of the specifications for this type.

The other machines manufactured by Mr. Potez are mostly of a commercial type and are of no special interest from an air service viewpoint.

WIBAULT MACHINES.

The Wibault Co., headed by Mr. Wibault, has made a great contribution to France and to aeronautics by their new all-metal bomber. The machine is bold in design and thorough in detail, embodying most of the French requirements.

The machine, known as the Wibault B. N. 2, is an all-metal biplane for night bombardment. It is powered with a Renault 600-horsepower motor and has the following characteristics:

Length, over all: 41 feet 10 inches.
Span: 55 feet 6 inches.
Height: 16 feet 5 inches.
Wing area: 1,035 square feet.
Engine: 600 horsepower Renault.
Weight, empty, but with cooling water: 4,620 pounds.
Useful load: 3,100 pounds.
Fuel for four hours at 6,500 feet; 160 gallons.
Total loaded weight: 9,450 pounds.
Speed at 6,500 feet: 125 miles per hour.
Wing loading: 9.1 pounds per square foot.
Power loading: 15.8 pounds per horsepower.

This machine is the most interesting type of all-metal construction that was seen in France with the exception of the Breguet Sesquiplan. One of the striking features of this machine is the location of its bomb and gas loads, which are entirely disposed within the fuselage of the machine. This affords a streamlined outline for the ship, irrespective of the nature or kind of load carried and does not detract from the ultimate performance by added resistance of external bomb installations such as is found in the majority of military machines.

The wing truss is of the single-bay type. The top wing is shorter than the bottom wing. The reason for this, according to Mr. Wibault, is the structural advantage in the saving of weight, due in this case to the higher structural resistance to the compressive axial ends loads induced under maximum stress conditions in the upper wing. It also permits ease of alignment in the field and reduces parasite resistance to a minimum. The wing ribs are built up of duralumin tubes in trellis structure fastening with duralumin gusset plate joints. This makes a very rigid rib without any weak joints. It represented the very safest type of built-up rib that was found in Europe.

The spars are built of duralumin. The face webs are the flange type with lightening holes, produced by bending at right angles along straight lines and by supplying a radius near the flange that supports the flanged edges. This construction is advantageous inasmuch as the flanges can be made without the expense of costly dies for stamping. The spar flanges themselves are flat strips of duralumin riveted to the flanged edges of the webs.

The wings have withstood a load factor of seven and a half without showing any permanent deflection, and to all appearances the detail wing construction was in very good condition.

The fuselage is of the Breguet type of duralumin tubing and steel fitting construction. The tail planes are built up similarly to the wings. The pilot and gunner are situated far back in the fuselage. In fact they are halfway from the trailing edge of the wings to the sternpost. The vision aft and overhead in this case is very good, but the vision forward is quite questionable and is receiving criticism. The crew is well protected in case of a crash and this machine fulfills its night bombardment mission very well. This arrangement has been carried out with the idea of locating the fuel and bomb load as near to the center of gravity of the machine as possible so that the variation in useful load will require very little time and attention of the pilot to the tail adjustments.

The landing gear is of the conventional twin V rubber shock-absorbing type. The machine uses Lamblin radiators, one of which is mounted on either side of the fuselage near the engine.

Mr. Wibault is working on a pursuit machine of the Hispano 300-horsepower motor. It will be all-metal with the general structural characteristics of the bomber. However, it will be semi-internally braced with struts projecting from the bottom of the fuselage to halfway out on the wings.

The performance is theoretical and claimed by the Wibault Co., but their high estimate is probably very optimistic.

Characteristics:

Motor, Hispano: 300 horsepower.
Rateau supercharger.
Span: 11.400 meters.
Length: 8.50 meters.
Useful load: 450 kilograms.
Speed at 3,000 meters: 300 kilometers per hour.
Ceiling: 12,000 meters.

MORANE SAULNIER.

The Morane Saulnier Co. has been engaged in wing experimentation on their regular type A. R. 80 horsepower Le Rhone parasol monoplace. They have changed their old conventional thin wing to an internally braced thick wing. This change has been made simply with the idea of study and to get full-scale data on the relative advantages and disadvantages of this new thick wing over that of the preceding thin wings. This wing is braced practically Fokker fashion.

The characteristics of the machine with this new wing are as follows:

Span: 8.90 meters.
Surface: 13 square meters.
Load empty: 545 kilograms.
Useful load: 140 kilograms.

The object of this test has been to obtain a suitable wing for their two-place Corps d'Armée.

The most important development work being done by this company is their three-motored monoplane. It is the internally braced type of tapered wing with two of the engines located in the leading edge of the wing. It is all-metal construction. Full description of this plane is given in this report under the heading "Résumé of French research, development, and service aircraft" on pages 7, 8, and 9.

Basic characteristics of this machine are as follows:

Span: 93 feet.
Length over all: 56 feet 8 inches.
Height: 10 feet 5 inches.
Chord maximum: 19 feet.
Area: 1,300 square feet.
Engines: 1,200 horsepower.
Weight, empty: 9,500 pounds.
Weight, loaded: 15,500 pounds.
Estimated high speed: 150 miles per hour.
Estimated ceiling: 15,000 feet.

FARMAN AIRCRAFT.

Farman has continued to use the old, conventional type of stick and wire construction, but has developed some efficient weight carriers. He has, however, built considerably in metal also.

THE FOUR-MOTORED 1,500-HORSEPOWER FARMAN.

The latest addition to the Farman group of ships resembles closely and shows a marked influence of the famous Farman Goliath. It is powered with four Lorraine-Dietrich engines, the power eggs being situated on the lower wing at the first strut station, directly over the landing gears. Each power group has two motors in tandem. The fuselage carries an auxiliary landing gear attached to the front to prevent nosing over. The mechanics can go out to the motors and attend to any light repairs or make adjustments necessary to their functioning in flight. It is also provided with a wireless cabin.

This immense machine has a—

- Span: 34.50 meters.
- Total length: 22 meters.
- Total height: 7.50 meters.
- Chord: 4.65 meters.
- Gap: 4.65 meters.
- Total surface: 300 square meters.
- Weight, empty: 6,000 kilograms.
- Useful load: 4,500 kilograms.
- Total weight: 10,500 kilograms.
- Speed at sea level: 160 kilometers per hour.
- Ceiling: 4,500 meters.

Owing to the difficulty of packing and shipping these enormous wings, the trailing edges are removable. This machine is now at Orly undergoing assembly for preliminary tests.

FARMAN GOLIATH.

Fifty Goliath type bombers are being built for the French Government. They are motored with two 235-horsepower Salmson motors in nacelles mounted on the bottom wing. They carry approximately 1 ton of bombs and seven hours' gas. However, Mr. Farman would prefer the machine with motors of the 270-horsepower, Renault type, due to the fact that a lot of trouble has been experienced with the Salmson engines. These bombers have been designed to fulfill night bombardment specifications and the characteristics of this machine in toto will be found in our files.

Thirty-five of the Farman Goliath type have been constructed for transport work and are about completed.

One of this type of ship has been built and remodeled to be used as a flying laboratory. The rear compartment contains a finder which is nothing more nor less than the usual insulated loop on the pivoted frame. Next is the radio operator's cabin, which is equipped to allow the operator to sit comfortably and have easy access to two tables on which instruments would be mounted. The cabin is almost soundproof and is shut off by a door from the rest of the ship. The radio sets have a radius of action of 300 kilometers with the telephone sets and 500 kilometers with the telegraph sets. A passage leads from the pilot to the navigator's cabin, which is provided with plenty of space to work and keep charts. The navigator can go out of his cabin and take sight with a compass.

In front of the radio cabin is the pilot's post. The pilot is on a raised platform on the left side of the machine and has a fair vision. There is no dual control. The machine is being used to try automatic stabilization on the lateral controls. The wheel is provided with a straight tube grip which is superimposed from the base of the wheel to allow control of the elevator surface without interference with the lateral controls.

A very excellent magnetic compass is placed in front of the pilot, but as the wheel is sometimes apt to obstruct his vision, the compass is provided with a prism which enables him to see it at all times. The compass is illuminated in the usual way. The compass is so equipped with a prism and a light that the navigator sees his sighting point and the compass reading at the same time. The compass is mounted on a slide so as to allow it to be lowered and pulled within the adjustable top of the compartment.

Another interesting instrument is mounted in the pilot's cockpit but was not seen in the machines at the factory. It is merely an adaptation of the disk system of communication between navigator and pilot. Two disks which are identical are provided with hands which can be moved by either pilot or navigator and about 25 form messages can be sent. A wire runs over two small pulleys which are fixed to the hands and actuates them. The installation is very good, but it could be improved by the addition of enough spaces to allow words to be spelled out. The instruments could be provided with a tape to record automatically the message sent. This presents no difficulty and would be a good auxiliary means of communication. The real way to communicate between pilot and navigator is by word of mouth.

A slightly different type of flight indicator and inclinometer is also provided. It consists of the usual gyro mounted vertically and provided with a small mirror mounted on top. A source of light beam is provided by a small electric bulb. The mirror reflects the beam on a translucent dial, which is fixed on an adjustable base mounted directly on the plane so that the beam shows whether the machine is flying level, climbing, or drooping a wing. It should show whether the machine is turning, and possibly it does, but centrifugal force may commence to act on the gyro and the usual precession take place, which may or may not interfere with the accuracy of the reading. The instrument will allow the pilot to climb the ship at the best possible climbing angle and glide at the flattest glide. In its present interpretation, the instrument is not very remarkable except for being a different application of old and well-established principles. They might be infused into one instrument, which in fact could be made a turn indicator, flight indicator, inclinometer, gradometer, airspeed meter, and a device to show best glide and climb.

The navigator is also provided with a turn indicator or derivimeter S. T. Aé. and bomb sight in one. It is the old principle of a hole in the floor provided with a series of adjustable parallel lines in such a way as to allow objects to move along these lines and then read the angle. By means of a sight graduated for altitude, it is possible to read the ground speed by applying the time coefficient to the graphic chart provided. Windows in the side of the navigation cabin give ample lateral visibility.

FARMAN TWO-PLACE OBSERVATION TYPE A-2.

Farman is at present constructing 100 of these machines which are built of duralumin shapes and powered with the 260-horsepower Z 9 type Salmson engines. The job is a dual control with a deep, roomy cockpit for the observer. It is a conventional two-bay machine and from outside appearances does not seem to be especially novel, but the performance is reported to be especially satisfactory. It carries three hours' fuel and oil.

Characteristics:

Span: 12 meters.
Area: 37 square meters.
Weight, empty: 895 kilograms.
Weight, full load: 1,420 kilograms.
Load factor imposed in static tests: 8 plus.

The flight tests conducted by the French technical section with a load of 525 kilograms gave the following results:

Ground speed: 191 kilometers per hour.
Speed at 5,000 meters: 175 kilometers per hour.
Ceiling: 6,600 meters.
Climb to 2,000 meters: 7minutes 30 seconds.
Climb to 3,000 meters: 12 minutes 35 seconds.
Climb to 5,000 meters: 28 minutes 35 seconds.

The weight of this machine is remarkably light when one considers the weight empty and the heavy useful load that it carries per horsepower.

FARMAN TORPEDO PLANE.

The Farman torpedo plane is a two-place biplane with the bottom of the fuselage hollowed out to receive a torpedo. It is powered with the 450-horsepower Renault. It is entirely constructed of wood.

Characteristics:

Span: 18 meters.
Length: 13 meters.
Area: 100 square meters.
Weight: 3,200 kilograms.

This machine is not capable of landing at sea, but has a landing gear quite similar to the Farman Goliath. The fuselage is divided up, however, into water-tight compartments so it would float in case of forced landings at sea. It has a conventional two-bay wired wing truss and all control surfaces are counterbalanced.

HANRIOT.

The Hanriot Co. has designed and constructed at large the following well recognized and known types:

Type HD-1. Single-place acrobatic pursuit.
Type H. Powered with the 120 Le Rhone engine.
Type HD-2. Single-seater seaplane pursuit; powered with the 130 Clerget.
Type HD-3. Two-place pursuit; powered with the 240-horsepower Salmson engine.
Type HD-6. Combat; two-place; powered with the 500-horsepower Salmson engine.
Type HD-7. Single-place; high altitude; pursuit; with the 300-horsepower Hispano.
Type HD-9. Corps d'Armée reconnaissance for long distance; single-place; powered with 240-horsepower Salmson.
Type HD-12. Single-place pursuit.

TYPE HD-12. SINGLE PLACE-PURSUIT.

The HD-12 is of the conventional Hanriot stick and wire construction with characteristics as follows:

Span: 9.60 meters.
Length: 6.15 meters.
Height: 2.50 meters.
Area: 25 square meters.
Motor, Le Rhone: 180 horsepower.
Weight, empty: 470 kilograms.
Maximum speed: 190 kilometers per hour.
Speed at 3,000 meters: 187 kilometers per hour.
Climb to 1,000 meters: 2 minutes 39 seconds.
Climb to 3,000 meters: 9 minutes 14 seconds.
Absolute ceiling: 7,250 meters.
Service ceiling: 6,750 meters.
Endurance: 2 hours.
Useful load: 150 kilograms.
Load factor: 7.

This machine has been specially designed for taking off from ships' decks and is very well adapted for this type of work, as was evidenced in flights from the deck of the *Berne* at San Raphael. Pilots like the machine very well for this kind of work. Although the maximum speed is not great, still it has very good qualities of maneuverability and climb, a low landing speed, and quick takeoff, which give it the essential qualities for shipboard use. The visibility is very good. The performances are equivalent to those obtained in the famous HD-1.

TYPE HD-14 TWO-PLACE TANDEM TRAINING MACHINE.

This machine has been a special study to permit the rapid instruction of pupils with the minimum risk to the pilots. It is a biplane equipped with the 80-horsepower Le Rhone engine. The construction is of the Hanriot stick and wire. It is very simple and permits easy and rapid replacement of any of the important elements.

This machine was designed especially for training purposes on an average airdrome. Its physical characteristics are a wide track landing gear formed by a double-skid twin chassis with independent vees. This construction tends to minimize accidents in getting off and in landing on rough grounds. This machine was tried out by the French technical section at Villacoublay. It gave results which classified it as one of the most effective types of training machines in France.

This machine featured a Hanriot dual mechanism of the quick-release type which allows the pilot to disorganize the student's control while in flight by a simple cam action.

The principal characteristics are as follows:

Span: 10.40 meters.
Area: 34.5 square meters.
Total length: 7.25 meters.
Weight, empty: 529 kilograms.
Weight of fuel: 84 kilograms.
Useful load: 170 kilograms.

Performances realized are as follows:

Maximum speed at ground: 120 kilometers per hour.
Minimum speed in flight: 70 kilometers per hour.
Climb to 1,000 meters: 6 minutes.
Climb to 3,000 meters: 30 minutes.
Ceiling: 4,700 meters.

The Hanriot Co. is engaged in turning out 75 of these machines for the French Government, as well as many for foreign Governments.

HANRIOT TYPE 14 BIS.

This machine is practically the same as the HD-14 with the exception of its power plant equipment. It has a Clerget 130-horsepower motor and a more simple, conventional type landing gear. These changes were made to cut down head resistance and in order to obtain a more advanced training machine with great speed and better performance. It is really only a machine for more advanced training than could be given with the 80-horsepower Le Rhone motored HD-14 type.

HANRIOT TYPE HD-17 TWIN FLOAT NAVY TRAINING MACHINE.

This machine is practically the same as the HD-14 except for the adaptation of twin floats which are attached to the same points as the landing gear and the adaptation of a 130-horsepower Clerget motor in place of the 80-horsepower Le Rhone. This machine has a balanced twin-float system and a small tail float in place of the tail skid. The general characteristics are the same as the HD-14 training job. The weight, in order of flight, is about 1,000 kilograms. The weight, empty, is 740 kilograms. The maximum speed at sea level is 120 kilometers per hour. Its ceiling is 4,000 meters. Qualities of flight and maneuverability are quite identical with the conventional HD-14 type.

HANRIOT STUDENT DISENGAGING DUAL CONTROL.

The Hanriot student disengaging dual control from the pilot's cockpit is the best interpretation of the type that has been developed to date and a type similar to it, or functioning equally as well, ought to be installed on all our training types. An assembly drawing is available showing principles of installation and operation.

HANRIOT METAL CONSTRUCTION.

While still devoting their productive efforts to the construction of stick and wire machines, the Hanriot Co. has fully realized that the era of metal is at hand and are doing some experimental work along metal construction lines.

This metallic construction is evidenced in one case by a two-seater 300 Hispano motored, supercharged, high-altitude, pursuit airplane of steel tubing. This machine is at present in the experimental state and has not been flown to date. It is a first step, and we may well expect progress.

Hanriot machines have always been well built and practicable. This has followed through their long line of conventional models. Now that their engineering division has gone into metal, it is not too much to expect them to turn out a first-class, all-metal machine in the near future.

DURALUMIN.

France realizes fully the value of duralumin for the manufacture of aircraft. She has encouraged the development of the industry in every way possible and at the present time is able to secure an adequate supply of this metal. In order to take advantage of the facilities of the French air force technical section and to be near the center of aircraft development, the Society Duralumin have located one of their plants on the outskirts of Paris which devotes its entire energy to the manufacture of duralumin for aeronautical construction.

This plant was inspected. A great amount of development and experimental work has been done, but every operation is now reduced to a production basis. Facilities are available for conducting every necessary test to determine whether the finished product meets specifications. The plant has a competent force of skilled workmen that would form the nucleus of a great plant should quick expansion become necessary.

The metal is prepared in the usual way and run into tubular molds. From outward appearances there is nothing unusual about the molds. They are clay-lined and vary in size with the size of stock desired. The stock is removed from the molds and the rough ends sawed off. This is done with an ordinary bandsaw. The pieces are then cut into lengths of about 18 inches.

The lengths are pierced by driving a hole through them with a pressure press. The press used for this purpose is a 500-ton press. After the length is pierced it is placed in another press of double the power and the length is forced out of the press in tubular shape. The processes are very rapid and simple.

The tubes are then handled in lengths of 15 feet. Cranes are used for conveying them. About 20 or 30 tubes are heat-treated at once and then plunged in a bath. This process is one that requires very exacting control of temperature, for a change of 15° in the bath will give the metal essentially different characteristics and it will not come up to the test requirements.

After being heat-treated the tubes are sawed off angularly at one end to allow for the jaw of a special machine that is used either to make the tubes perfectly round or any shape that is desired. The tube is pulled through a die that shapes it so that it is ready to be used as a spar or longeron without further process. The tubes then go to the inspection room, where they are carefully scraped and examined for flaws and are given specification check.

Samples of all the various shapes and sizes were procured and have been forwarded to the Chief, Air Service Engineering Division, Dayton, Ohio.

FRENCH MOTORS.

Motors are classified for consideration of their characteristics from a technical viewpoint by taking into account the system of cooling, whether air or water cooled, the disposition of the cyclinders, their location, volumetric efficiency or compression, motor regulation, and speed of rotation.

Lightness is a characteristic requirement for all aircraft motors. The latest representative French air-cooled job is the Le Rhone 180 horsepower rotary engine. To date they have failed to develop radial air-cooled motors of high horsepower. For motors of about 300 horsepower, the most efficient French engine from the consideration of weight in pounds per horse power, consumption per horsepower, cooling surface resistence per horse power and for high-altitude work, is still the 300 Hispano-Suiza.

The French Rateau superchargers are in service and are being further developed for pursuit and bombardment planes. The French adaptation of Rateau superchargers has been made and is being carried on experimentally with the French 300-horsepower Hispano-Suiza and Renaults of the 350, 450, and 600 horsepower types. The Rateau supercharger has been very well developed and physical evidences of plane installation is illustrated in the French Nieuport 29, the single-motored Breguet day

bombardment type with Renault engine, and the Spad two-seater observation plane.

The lower horsepower French motors are made up of types from 60 to approximately 330 horsepower, and practically all have direct drives. These are found in the majority of military types and are: The Renault 300 horsepower, Salmson 260 horsepower, Le Rhone 270 horsepower, Le Rhone 120 horsepower, Le Rhone 180 horsepower, Clerget 130 horsepower, Hispano-Suiza 150 horsepower, Hispano-Suiza 180 horsepower, Hispano-Suiza 200 horsepower, Hispano-Suiza 220 horsepower, and Hispano 300 horsepower. Motors of 400 horsepower and over run at speeds of about 1,300 to 1,600 revolution per minutes. The principal of these are the Renault 450 horsepower, Renault 600 horsepower, Lorraine Dietrich 400 horsepower, and Salmson 350 horsepower. These types are practically developed for field service.

French motors with reduction gears are rare and the only one that has been very much in evidence is the 220 horsepower Hispano-Suiza, which has never been very successful. The Lorraine-Dietrich 1,000 horsepower engine is still in the process of development. The only installations for the 160 and 180 horsepower rotary Le Rhone were in the Hanriot and Nieuport experimental pursuit types.

French opinion has not crystallized as to what the most desirable types of motors will be. Experimental work is still being done on the semi-Diesel and internal combustion types. It is evident from their practice to date that, in spite of the interest in aeronautical circles in obtaining a motor with fuel which is less inflammable than gasoline and their desire to reduce the fire hazards, gasoline engines still prevail. Trials with alcohol have shown that with a compression ratio of about 6, the same thermodynamic efficiency can be obtained as with gasoline, but the consumption is much greater.

With the advent of motors of increased horsepower, the question of light construction must receive serious consideration. From a weight per horsepower standpoint, the difficulties with air-cooled motors will likely be more assertive in weight horsepower ratio beyond the 400-horsepower type. Difficulty will be experienced in decreasing the resistence of the greater horsepower motors. The logical type to develop in water-cooled motors is one weighing 2 pounds per horsepower and producing 450 horsepower of the V type, capable of an endurance of a couple hundred hours. This is the type the French are trying to develop at present.

The short life of motors between overhaul is one of the disadvantages incidental to all the various water-cooled engines which the French hope to offset in a large measure. To realize this, they have instituted a motor competition for the design and development of a 450 horsepower engine that will have a life of 240 hours. They are offering a prize of 2,000,000 francs for the best motor designed embodying these characteristics. When this type has been perfected, it can be easily adapted to their pursuit and bombardment types, either with or without superchargers.

The characteristics of the Renault 600-horsepower engine are as follows:

- Cylinders: 12. Bore and stroke: 160 by 180.
- Cylinder displacement: 43. Leaders: 410.
- Compression ratio: 5.3.
- Power: 575 horsepower at 1,600 revolution per minute.
- Total weight: 560 kilograms.
- Consumption per horsepower:
  - Gasoline, 260 grams.
  - Oil, 25 grams.
- Ignition: 2 magnetos, double ignition.
- Carburetors: 2 Zenith doubles, Model 75 D 1.
- Controls built into motor.
- Cylinders separate, with steel water jackets.
- Pistons: Aluminum.
- Water pumps: Centrifugal type, two outlets.
- Carburetor and spark control countershafts and rods are directly fixed to engine as part of assembly.
- Four oil pumps.

Ten of these models have been delivered to the French Government and orders have been placed for 100 more. The first installation evidence of this motor has been in the Wibault night bomber. The 450 and 300 horsepower types are well known and do not require any description in this report. They are much in evidence in airplane installations of the Breguet types.

The Wright and Curtiss engines represent better pursuit engines than any the French have developed to date, from a standpoint of weight per horsepower, radiator surface required, and performance attainable. The Liberty motor surpasses in reliability, weight, and power ratio any of the French analogous types.

The progress in motor development in France has been retarded to a certain extent by the mass of war-time motors which are still on hand. A table follows, showing all French motors, giving the number available, their horsepower, weight, and the class of planes in which they can be used. By weight in the table is meant the radiator, water, oil, motor base, silencer, propeller, etc. The word "cannon" means a motor with a cannon shooting through the crank shaft. In referring to the plane in which the motor can be utilized, reference is made by using the French type specification identification, which is as follows:

- Pursuit:
  - Monoplace pursuit for high altitudes, C.1.
  - Monoplace pursuit for low altitudes, c.1.
- Pursuit and reconnaissance:
  - Biplace pursuit or reconnaissance, C.Ap.2.
  - Biplace pursuit and night reconnaissance, A.An.2.
- Observation:
  - Biplace, C. A., and divisional, A.2.
  - Biplace, C. A., and divisional, Ad.2.
  - Armored biplace for divisional squadrons, Ab.2.
- Bombardment:
  - Biplace, day bombardment, long distance, Bp.2.
  - Biplace bombardment or attack, BS.2.
  - Triplace of protection for the day bombardment, Bpr.3.
  - Biplace, lightly loaded for day bombardment and combat, Bn.2.
  - Multiplace, heavily loaded, night bombardment, long distance, Bn.4.
- Colonial.

Available motors for military aricraft.

Supply.	Type.	Horse-power.	Weight (in pounds).	Type of airplane.
20	Bugatti cannon	450	815	
1 experimental	De Dion	800	1,330	CAn.2.
Long series	Hispano	300	450	Bp.2.
10 on order	Hispano with Rateau	275–300	500	C.1, c.1, C.Ap.2, Bpr.3.
1 in study	Hispano cannon	400–450	....	
1,000	Liberty	370–400	600	A.2, BS.2.
Long series	Lorraine	270	420	CAn.2, A.2, BN.2.
700	...do	370	600	CAn.2, A.2, BS.2, BN.2.
1 building	Lorraine with gears separate	370	680	BN.2, BN.4.
1 experimental	Lorraine	500	760	CAn. 2, A.2.
200	Panhard, geared	330–350	675	
1 experimental	Panhard	500	850	C.1, c.1, C.Ap.2, CAn.2.
Do	...do	500	825	BS.2.
Do	...do	600	1,000	C.1, c.1, C.Ap.2, CAn.2, BS.2.
Do	Peugeot	500	825	A.2, BS.2.
Long series	Renault	280–300	510	CAn.2, A.2.
	Renault with Rateau	280–300	570	C.1, c.1, Bpr.3.
For study	Renault with reduction gears separate.	570	....	BN.2, BN.4.
900	Renault	380–450	720	A.2.
4 on order	Renault with Rateau	380–450	810	C.1, c.1, Bp.2, C.Ap.2.
1 in study	Renault with reduction gears	380–450	....	BN.2, BN.4.
10 experimental	Renault	550–600	940	C.1, c.1, C.Ap.2, CAn.2, A.2.
1 being studied	Renault with Rateau	550–600	1,020	C.1, c.1, Bp.2, CAp.2, Bpr.3.
Long series	Salmson	230–260	385	CAn.2, A.2.
25	.....do	460–550	....	C.1, c.1, C.Ap.2.
Long series, rotary	Clerget	130	190	BS.2.
	...do	200	270	
	Rhone	120	175	
	...do	170	200	

HANGARS.

Hangars and hangar construction can well be considered under a discussion of French aeronautics, since that country has examples of every type of hangars that are to be found in Europe. Some of these are distinctly German but have become the property of France through the terms of the treaty of Versailles.

Five huge hangars have been constructed at Le Bourget, on the outskirts of Paris, which are intended to house the huge military and commercial airplanes of to-morrow. They will be used immediately as a part of the equipment of the Paris air port.

These huge structures are 125 feet wide by 250 feet long and are built of concrete and steel. The floors and hangar wall bases are of concrete and the main structure is built of steel trussing with main frames pin-jointed to the hangar base. The doors are of the overlapping panel type and are electrically operated. When the doors are entirely opened the total floor area consumed, due to the overlapping of all the door panels, is not any greater than one door panel. The doors are very thick and are of steel truss structure mounted on huge truck wheels. These engage with a track running parallel with the face of the hangar and are guided at the top by rails and wheel guides. Careful attention has been paid to reduction of the rolling friction to a minimum, and these doors have been found very easy to open and close.

The heating of these hangars will be by a hot-air system, and the intention is to keep the hangars at a temperature about 10° above that outside. On each side of the hangars small storerooms and workshops have been built.

The lighting system is very unique. It is effected principally by skylights that have been incorporated in the construction. These hangars are constructed to be permanent. Many others are to be constructed in addition to those already begun.

Another type is the new dirigible hangers that are being built at Orly to house the large dirigibles that the French Air Service expects to construct. These hangars will be entirely of concrete construction with the internal truss. They are of the crown type with sloping sides and with huge concrete abutments. They are designed so as to resist the effect of possible bombardment from the air.

These hangars will have a free space of 150 feet and are 1,000 feet in length. They constitute an enormous project, representing the expenditure of a huge sum of money, and are conclusive evidence of the faith that the French have in the future of military and commercial aeronautics.

A free space is provided around these hangars so as to obviate as far as possible the danger of fire and to limit the amount of damage in case of explosion from any cause whatever. The hydrogen plants, which are of permanent construction, are also isolated and far from any of the more important buildings.

The hangars occupied by the French bombardment regiment at Neustadt constitute an interesting study. This airdrome was constructed and occupied by the Germans during the war. The hangars are not high enough but are well constructed throughout. The construction is of concrete with concrete floors. Most important is their unique heating system. Underground hot-air pipes empty into several floor vents about 6 inches in diameter located about every 25 feet. They are practically underneath the stall space that would ordinarily be occupied by an average machine. These holes are flush with the floor surface and can be covered with ventilated cover plates.

In cold weather little hot-air stoves can be installed over each of these holes to allow better diffusion of heat. Keeping the mechanicians warm greatly increases their efficiency. Flexible Greenfield type duralumin hose is also provided in all these hangars in different lengths to allow heat to be carried to the individual machines at night. The motor compartments are thus supplied with hot air from the outlet vents in the floor. The idea is to keep the oil in the motor compartment from congealing during cold weather and to facilitate starting. No interference with the passage or location of the machines in the

hangars is occasioned on account of these installations. This individual piping of hot air to the machines at night in cold weather was the only instance that was noticed in any of the hangars abroad.

Zeppelin hangars are being transported from Germany to France and to Italy and are being installed at Cuers and Cianpiano. At Staaken, just outside of Berlin, a steel Zeppelin hangar is being dismantled for shipment to France. The doors of this huge hangar are of the semicircular panel type, opening in an arc.

The airplane hangars occupied by the French along the French-German frontier in the temporarily occupied zone where hangars were not already existing are of the Bessoneau type. These are the well-known type with demountable wood frame and canvas covering. However, several airdromes which are now occupied by the French were formerly occupied by the Germans, and hangars of semipermanent and permanent construction are found.

We can very well take a lesson from the experiences of the Allies as to methods of hangar and door construction, heating and lighting. Door suspension and handling are vital to the life of a hangar, and it is essential that they be capable of being opened and closed easily and quickly to permit ingress and egress of machines under all weather conditions with the use of a minimum number of men.

LAMBLIN RADIATORS.

The Lamblin type radiator is being used in France on practically all the latest types of airplanes. A great deal of foreign criticism has been directed at this type of radiator on account of the apparent difficulties of manufacture. The difficulty of making repairs, of mounting and of transporting, have also been criticized.

The primary reason advanced for the use of this type of radiator is the simplicity and ease with which it can be placed in a free-air position apart from the fuselage or wings. Most installations have been underneath the fuselage and in the landing gears. However, others have mounted them on the sides of the fuselage and on the bottom wing. This radiator minimizes the parasite head resistance required for cooling the motor. The best installation is the one used on the Nieuport 29, and claims have been advanced that the fine performance and speed characteristics of this airplane are attributable in no small measure to the low resistance of the Lamblin cooling system. The French Air Service has placed orders for 200 of the Nieuport 29 single-seaters with Lamblin radiator installations, which is significant of their faith in the merits and serviceability of this type.

The radiator mounting on the Nieuport 29 is of the twin support type and allows for ease of demountability in the fields. Some designers stated that the Lamblin radiator aids them in balancing their machines on account of the simple nature of the mounting required and the ease of moving the position of the radiator.

The radiator in itself is rather expensive to construct. It consists of about 100 elements. The manufacturers stated that there were approximately 4,500 operations in the completed radiator and that all the radiator elements are alike and interchangeable. The radiator elements allow a very high degree of expansion and are said to hold up very well under freezing conditions. The elements can be readily detached in the field by unfastening five soldering wires, the inlet and outlet collector ring, and the two annular circuiting rings. Samples of the elements in their various stages of manufacture were procured in order to furnish our engineering division with first-hand information as to the actual problem in the manufacture as well as the facility of repair. These have already been forwarded to the chief of the engineering division.

They are nested in felt-lined cradles and are mounted singly or in pairs in boxes for transportation. These radiators cost about $100 apiece in France.

EX-GERMAN ZEPPELIN "L-72."

The *L-72* was surrendered by the Germans to the French under the terms of the treaty. It is fully assembled in the hangar at Cuers. It is supported by blocks all along the frame. Parts of the motors have been removed from the nacelles and all are well blocked to take the weight off the frame. The spares are well stored in rooms along the side of the hangar and are receiving good care.

The great ship was thoroughly inspected and we were impressed mostly by the lightness of her construction and the perfection of the detail. Her frame is all built of triangular truss construction. She has a keel that runs from one end to the other inside her envelope that is somewhat similar to the keel in the *Roma* but inverted. Of course it is not flexible. This keel is the support to which the cat walk and all the tanks, ballast, compartments, etc., are attached.

Tke *L 72* has been renamed the *Dixmude* by the French. She is 227 meters long and 24 meters wide. She has a radius of action of 18,000 kilometers at 50 kilometers per hour, or will carry 7 tons of bombs for 12 or 15 hours at the same speed. Her normal crew is 5 officers and 25 men. Her officers are a commanding officer, three watch officers, and one officer mechanic. Plenty of sleeping quarters are provided and a fairly comfortable room for the officers and another for the commanding officer is built inside her envelope. No provision is made to cook food aboard.

This ship was built primarily to carry a load of bombs for a short distance at a great altitude. The tail surfaces are all internally braced but have a few wires on the outside as well for additional strength. She is motored with six Maybach motors of 245 horsepower, placed one in a rear nacelle underneath and in the middle, two pairs of two each along the sides and one immediately in the rear of the navigating cabin which is the middle of the ship in front. The front and rear motors turn 890 and the others 1,600 revolutions per minute.

The French reported that the ship was all ready to be used with the exception of the balloonets. These the French do not have. As it will require 200,000 cows to get the gold beater skins to make them, the *L-72* will likely be out of commission for some time.

The acquisition of the *L-72* has been a good thing for the French, for they have learned much from it that will be of great value in their lighter-than-air development.

FRENCH METEOROLOGICAL PILOT BALLOONS.

The French are using a simple device which is not only accurate but which saves considerable time in the inflation of their pilot balloons. This is merely a loaded brass spring valve constructed so that one end of the

valve fits into the throat of the pilot balloon and the other end into the hose of the hydrogen cylinder. The valve is so constructed that it can be weighted with sand or shot to the exact degree of buoyancy that the pilot balloon should have. The balloon is slightly overinflated and then the string placed on the valve. Gas is released until the balloon is in equilibrium and then the balloon is tied and the valve withdrawn. This simple device saves time.

PESCARA HELICOPTER AND HELICOPLANE.

Mr. Pescara has done a great amount of work to perfect a helicopter, and recently won the prize offered by the French technical section for the construction of a helicopter that would lift itself and pilot from the ground a distance of at least 1 meter and return to earth without mishap.

More recently Mr. Pescara has been devoting his energies to the production of a machine embodying the principles of both a helicopter and an airplane which he has styled a helicoplane. He stated that he had already received an order from the French Government to proceed with the construction.

This machine has upper and lower wings revolving in opposite directions. They are connected through gearing and clutches to a 300-horsepower engine situated immediately back of the wings in the fuselage. This motor is also connected through a clutch to a pusher propellor mounted at the rear end of the fuselage. The pilot sits immediately forward of the wings. The radiator is located in the front end of the fuselage. The machine will weigh 850 kilograms empty and 1,250 kilograms fully loaded. Surface loading will be approximately 80 kilograms per square meter.

The main vertical drive shaft to the helicoplanes proper terminates in the landing gear fork support and the vertical drive shaft housing alone forms the main support for the planes proper. Small counterbalancing ailerons are fitted at the extremities of the helicoplanes. Elevator, stabilizer, and rudder are mounted in conventional fashion. The tail skid is really an extra strut to the landing gear proper to keep the propeller away from ground interference.

In order to glide to earth in case the motor stops, Mr. Pescara claims that by varying the pitch of these helicoplanes and allowing them to be free to move they will revolve in opposite directions while gliding without power and thus increase the gliding distance appreciably. He claimed this would have practically the same effect as cutting down the loading to less than half of what it is with fixed planes.

Mr. Pescara is prepared to bring this machine to the United States under contract and guarantee its demonstration in a closed circuit under full control. Details of this arrangement can be procured from John M. Jahill, 334 Fifth Avenue, New York City. Mr. Jahill is Mr. Pescara's American representative.

ITALY.

RÉSUMÉ OF ITALIAN AERONAUTICAL ACTIVITIES.

Italy has had little incentive for the development of many new types of planes or motors since the war due to the huge accumulation of war supplies on hand.

The Italian Air Service has salvaged or otherwise disposed of the greater part of her old airplanes, but she has over 11,700 spare engines on hand, most of which have never been used, and with these figures always before them it is very difficult to convince the legislative bodies of the Government or the directors of the big industrial plants of the advisability of spending additional money for new engines. The result is that all designers of both new commercial and military types of airplanes are striving to create, and have created, better airplanes built up around the engines developed during the war. These engines have been in some cases considerably improved since the armistice by slight modifications. This is where Germany is more fortunate, from an aeronautical point of view, than any of the Allies, for having loaded all her obselete material upon the latter, she is free to direct all her studies, designs, experiments, and available money toward new constructions.

During the calendar year 1921 the following machines were produced:

Military machines manufactured for Italian Army	56
Naval seaplanes manufactured for Italian Navy	94
Commercial types produced	60

The 56 military machines were as follows:

Fiat BR, 700 horsepower	39
Macchi M 16 type	12
Miscellaneous	5
Total	56

The 94 naval machines, all seaplanes, were as follows:

Macchi M 7	50
Macchi M 18	20
Savoia S 13	18
Savoia S 12	2
R1 bis (3 IFV 6 motors)	2
PRB (4 IFV 6 motors now being changed to 4 Fiat A 12 bis motors)	2
Total	94

The commercial types constructed were as follows:

M 18 (seaplane)	6
S 16 (seaplane)	15
S 21 (seaplane)	2
S 22 (seaplane)	2
S 23 (seaplane)	2
Fiat type R	4
Ansaldo A 200	2
Ansaldo A 250	2
Ansaldo A 300, A 300 C, A 300 T	20
Breda triplane	1
Ricci R 9	2
Gabardini training machine	2
Total	60

Number and types, active service, army, per 1,000, are as follows:

Pursuit:	
Spad VII	96
Hanriot	144
Balilla	24
Bombardment:	
Fiat BR	24
Caproni 3	16
Observation:	
Samson	84
SVA	66
R2	12
School:	
Aviatik	200
Types above in same proportion	334
Total	1,000

Number and type, active service, in navy, are as follows:

Pursuit: M 7	40
Observation:	
S 13	30
M 9	50
Bombardment: Caproni 5	4
Total	124

Under orders for construction for the army:

Marchetti	12
Macchi	12
Ansaldo A 300	12
Caproni 450 (modified)	2
Stiavelli	2

Under orders for construction for the navy:

S 12 bis	10
S 23	2
S 25	2

Military types of machines built under war orders are being used in both the army and navy. Service squadrons will not be equipped with machines developed and constructed since the war prior to 1923. A few experimental types are constructed periodically as developed. If the types are found satisfactory at the experimental field and after a period of actual service with the experimental squadrons designated to give a service test to new types, they will be put into production to replace the old material. The first object will be to replace French types by new Italian types.

During the present year a special effort will be made to develop new military airplanes and engines in order to begin to equip the squadrons with new equipment during 1923.

Aeronautical technical research and development are being systematically carried out by the Institute of Experimental Aeronautics, by the Lighter-than-Air Constructing Establishment, by the Aerial Armament

Service, and by the Royal Polytechnic of Turin. The work of the latter place consists principally of aerodynamic studies.

The experiments and studies made at the Institute of Experimental Aeronautics are obtained by our military attaché, translated, and forwarded to Washington. Many of the studies made there are very important, especially those made by Colonel Crocco. Description and designs of the principal instruments used in their aerodynamic experiments, which were reported to the Engineering Division of our Air Service, should be very valuable.

The Lighter-than-Air Constructing Establishment has carried out interesting experiments with dirigibles, observation balloons, free balloons, and parachutes. The director gave us copies of reports on their most interesting studies and developments, which have been translated and forwarded.

The static test methods adopted by the Italians for testing out their aircraft have an embodiment of assumptions which are essentially different as regards the ultimate strengths required by aircraft under different flight load conditions. A copy in Italian of these standard test methods has been procured and is now being translated. However, a later and revised edition is now being prepared by the Italian Technical Experimental Institute and on completion of compilation will be tendered to our military attaché in Rome.

METAL CONSTRUCTION.

Mr. Dornier, of the Zeppelin Co. at Friedrichshaufen, intends to open up an airplane factory in Pisa and carry on the construction of his all-duralumin types of aircraft for Italian military and commercial purposes. This will, no doubt, have a strong tendency to revive interest and turn the trend of design toward all-metal construction in Italy. Italy has done very little with metal construction.

The only all-metal airplane in Italy to-day has been the Marchetti, which employs high alloy steel tubing for its basic construction. Their principal drawback for development in all-metal construction since the war has been lack of funds for experimental purposes, with subsequent reduced personnel and the lack of suitable materials.

In all new types steel is being almost entirely used for the following parts: Interplane struts; undercarriage struts; axles and practically the entire undercarriage; fuselage vertical struts and practically the entire framework of the fuselage except the longerons, which are of wood. The wing construction, spars, and ribs are entirely of wood. It is believed that the next stage of new construction in Italy will be the use of metal wing spars and the second stage will be the use of metal longerons in the fuselage construction. Some of the best engineers in Italy believe that a combination of wood and metal is the best for airplane construction. This is not the opinion, however, of the Experimental Institute. There, it is believed that in the near future the best airplane will be all-metal. Due to the lack of minerals in Italy, the adoption of metal construction will naturally advance slowly. Very little practical use has ever been made of duralumin in Italy and steel is therefore being used at present for the metal parts. The Italians are also naturally much better wood workers than metal workers and this is another consideration which retards the adoption of metal construction.

The Italians have always been noted for their wonderful woodworkers and woodworking facilities. The characteristic type of construction adopted and used in the Ansaldo, Savoia, Macchi, and S. V. A. types are wonderful examples of wood craftsmanship and design.

The tendency of future Italian types as designed to meet their latest specifications will mean an absolutely new order of machines, designed and constructed under these new projects with desired performances, which, if realized, will by far eclipse all their present and previous types.

SEAPLANES.

Their seaplane designs are particularly up to date, and each successive type represents an advantage in refinement over its predecessor. They have not done much work in development of multimotored flying boats outside of the new twin-motored tandem Savoia type and the P. R. B. 1 four-motored tandem type. The only multimotored bombardment types they have really developed to date are the Caproni.

THICK-WING AIRPLANE CONSTRUCTION.

No airplanes have been constructed of the thick-wing construction. Mr. Pegna has been designing an eight-engine seaplane of this type and has been receiving technical assistance from the Experimental Institute.

ENGINES.

The Anzani Co. is the only one in Italy that has actively constructed radial air-cooled engines. This firm has, however, made no improvements of interest. Their types 90 and 110, of 95 horsepower and 116 horsepower, respectively, are the most powerful that have been constructed by this firm. These motors have given very satisfactory service in school machines. It is reported that the Breda Co. is experimenting with a small type radial air-cooled engine. So far no information has been given out concerning the experiment. It is of 60 horsepower approximately.

The adoption of the 300-horsepower Hispano-Suiza engines for their latest pursuit-work development and also in other types equipped with superchargers, if procurable, although they have not developed any of these to date, will give them pursuit airplanes equal to French and English prototypes.

ARMAMENT.

The Aerial Armament Service has been carrying out systematic studies for the development of an efficient aerial gas bomb. These studies are considered secret, and naturally no detailed information is given out concerning the results. In approaching the chief of the Aerial Armament Service on this matter the following general information was obtained:

(a) The object in view is to develop a bomb with the gas compressed to 100 atmospheres.

(b) To obtain a bomb that is not to explode on impact, but to permit a gradual escape of the highly compressed gas or gases.

The Aerial Armament Service has also recently made experiments with an aerial bomb with long-delay fuses developed by General Giampietro. The fuses of these bombs can be set for different bursting times, the maximum being six hours. These bombs are to be transported by airplanes and dropped over a selected zone, such as an industrial center; for example, the zone thus being subjected to explosions for six hours. At the end of five or six hours the zone will be bombarded again, thus keeping it continually subjected to explosions. The moral effect of such bombs in an industrial center would be very great. The fuse is reported to have worked satisfactorily at all settings up to six hours in the practical experiments carried out. General Giampietro stated that Japanese agents were trying to purchase this type of fuse.

FLYING BOMB, ITALIAN.

One of the most interesting things in bomb construction was an aerial torpedo bomb of about 12 kilograms that was designed for operation against distant objects, to be dropped from an airplane at a height of 1,500 meters. It is about 10 inches in diameter and about 5 feet in length. Its wing span is approximately 4½ feet with a dihedral of about 3°. The wings are braced in Warren truss fashion. It is the concussion type of bomb, carrying the charge in the nose. Directly behind the charge is a small compressed-air chamber. The compressed air actuates a gyro which maintains the stability of the bomb by holding the rudder in place. The elevator is set to maintain the correct gliding angle and then to dive vertically. This is done by connecting the elevator to a cam which is revolved slowly by the action of a propeller on the tail of the bomb. This propeller, of course, is actuated by the reaction afforded by the movement of the bomb through the air. The wing area of this bomb is about 8 feet. This bomb can be used for bombing objectives at a distance of approximately 12 kilometers, thus giving the airplane or dirigible dropping the bombs that point of advantage in distance against defensive antiaircraft fire from the objective to be bombed. It has been tried out by the Italian Air Service with satisfactory results.

NEW DIRIGIBLES.

One thousand one hundred cubic meter semi-rigid dirigible.—This new type is being developed primarily as a preliminary training ship for dirigible pilots and secondarily for coastal reconnaissance duty in time of war and for pleasure and touring in time of peace. One of this type is practically completed and will be seen at Ciampino. Its characteristics are:

Type: Semirigid, with perfect continuous keel.
Volume: 1,100 cubic meters.
Power plant: Two 6-cylinder, 35 horsepower Anzani, radial, air-cooled engines.
Speed: 75 to 80 kilometers per hour.
Endurance: 10 hours with one motor; 5 hours with two motors.
Crew: 2.
Passengers: 2 to 3.
Cost: 160,000 lire, or $8,000.

New 46,000 cubic meter dirigible.—The plans and detailed drawings for this new dirigible (semirigid) have been completed. The Government has not yet given the order to begin work due to lack of funds by the air service. Its characteristics are as follows:

Type: Semirigid, *Roma* type.
Volume: 46,000 cubic meters. (*Roma*, 34,000 cubic meters).
Power plant: 10 SPA 6-A motors, each of 200 horsepower.
Speed: Maximum 110 kilometers per hour; cruising speed, about 90 kilometers per hour.
Range: 7,000 to 8,000 kilometers.
Passengers: 30 to 40 comfortably; there will be four cabins, each 5 meters long.

One hundred and twenty thousand cubic meter semirigid dirigible.—Engineer Usuelli, the designer of the *Roma*, has just completed all the plans and detailed drawings for his new dirigible of 120,000 cubic meters. He is trying to interest the Italian Air Service in this matter in order to have the preliminary work well under way in order to construct the dirigible in one of the large hangars obtained by Italy from Germany, which is expected to be erected at Ciampino in the near future. The Italian Government has as yet made no definite decision in this matter. He showed General Mitchell a concise description of this type with its characteristics and cost of construction.

Experiments on dirigible rudders and elevators.—One of the O type semirigid dirigibles (3,600 cubic meters) at Ciampino has had the rear part of its envelope made rigid, and the elevators and rudders have been attached directly to this tail stiffening instead of being placed under the rear part of the envelope, as has been the practice heretofore in dirigible construction in Italy. The tail planes have been attached in a manner very similar to that employed in the Zeppelins. Experiments with this modified O type have been carried out.

Maximum speed has been increased from 91 to 96 kilometers per hour and better results are expected. From the results obtained it is safe to state that this system of tail planes and rudders will be adopted in all future dirigible construction in Italy.

ITALIAN TYPE SPECIFICATIONS.

The Italians are not building planes in large numbers at the present time. They have made a careful study of the aeronautical problem and have drawn up type specifications for their various types of planes.

For three months or more a board of aeronautical engineers (army and civilian) have been drawing up the characteristics to be required of new military types to be produced during 1922 and to be put in service in 1923. The types are the following:

Night bombardment.
Day bombardment.
Ground attack or battle airplane.
Tactical reconnaissance.
Strategical reconnaisance.
Day pursuit.
Night pursuit.

The required characteristics of each of these types have just been obtained. They are of interest and value and are attached hereto.

NIGHT BOMBARDMENT MACHINE.

(a) Crew: Two pilots. Dual control. Posts for two pilots seated side by side and must have excellent visibility. Two mechanic machine gunners.

(b) Armament: Two groups of Fiat machine guns with 1,000 rounds of ammunition, for forward and rear defense. One machine gun for firing downward.

(c) Installations: Fixed accessories for installing radio equipment (receiving and transmitting). Navigating lights; device for illuminating the ground when landing; internal lighting system for reading the instruments.

(d) Instruments: Oil and gasoline manometers (if the tanks are not of the gravity type, altimeter, tachometer, aerothermometer (for the radiators), speed indicator either Pitot or Venturi tube, compass, clock, inclinometer, and map holder.

(e) Bombs: One thousand kilograms of bombs. The installation must be capable of carrying two different types of bombs. It must be possible to carry two large bombs weighing 500 kilograms each.

(f) Endurance: Normal load of oil and gasoline sufficient for a flight of 4 hours and 30 minutes at a speed of 140 kilometers per hour, and at an altitude of 1,000 meters, with machine complete with crew, armament, installations, and bombs. The tanks must be capable of holding sufficient oil and gasoline for a flight of seven hours at a speed of 140 kilometers per hour at a height of 1,000 meters. In this latter case the load of bombs will be decreased in proportion to the increase in the normal load of fuel.

(g) Maximum velocity: With machine fully loaded and at an altitude of 2,400 meters the maximum speed must not be less than 150 kilometers per hour.

(h) Minimum velocity: Minimum velocity must not exceed 75 kilometers per hour at 500 meters with a full load of crew, arms, instruments, installations, and sufficient fuel for one hour's flight, but minus the load of bombs.

(i) Climb: Two thousand meters in not over 18 minutes with the machine fully loaded. (A machine is understood to be fully loaded when it carries the entire crew, arms, munitions, various installations, and instruments complete, the normal load of bombs, and the normal load of oil and gasoline.)

(j) Engines: The machine must be multiengined and equipped with mufflers; the motors must be accessible for the mechanics during flight.

(k) Coefficient of safety in the static test: The coefficient of safety in the static test with respect to conditions of a full normal load must not be inferior to 6.5. In every case this test must fulfill the rules prescribed by the Institute of Experimental Aeronautics for carrying out the static tests, due account being taken of the characteristics of the machine.

DAY BOMBARDMENT MACHINE.

(a) Crew: Dual control; the pilots are seated side by side; one machine gunner.

(b) Armament: One pair Fiat machine guns for rear firing, with large firing sector and an allowance of 1,000 rounds of ammunition; one fixed machine gun.

(c) Installations: Fixed accessories for installing radio equipment (receiving and transmitting) and camera.

(d) Instruments: Same as for night bombardment machine.

(e) Bombs: Normal load of bombs not less than 340 kilograms. The bombs to be arranged, if possible, inside the machine. The installations must be capable of carrying at least 500 kilograms of bombs (for short bombing trips). In this latter case the normal load of fuel is understood to be decreased proportionally. The installations must be capable of carrying at least two different types of bombs.

(f) Endurance: Normal load of oil and gasoline sufficient for a flight of five hours at a speed of 240 kilometers per hour at an altitude of 3,000 meters, with machine complete with crew, armament, installations, and bombs.

(g) Maximum velocity: With machine fully loaded and at an altitude of 2,000 meters the maximum speed must not be less than 260 kilometers per hour.

(h) Minimum velocity: Minimum velocity must not exceed 90 kilometers per hour at 500 meters with entire crew, fuel sufficient for one hour's flight and without bombs.

(i) Climb: Three thousand meters in not over 15 minutes, with machine fully loaded.

(j) Coefficient of safety in the static test: The coefficient of safety in the static test with respect to conditions of a full normal load, must not be inferior to 11. In every case this test must fulfill the rules prescribed by the Institute of Experimental Aeronautics for carrying out the static tests, due account being taken of the characteristics of the machine.

(k) Preference conditions: Under the same conditions, preference will be given to multiengined machines. Having the engines fitted with mufflers will be a preference condition also.

GROUND ATTACK OR BATTLE MACHINE.

(a) Crew: One pilot and one machine gunner; machine with dual control.

(b) Armament: Two fixed machine guns in front for firing forward and one pair in the rear for rear fire, and device for firing downward. Aggregate weight of machine guns and ammunition, 200 kilograms at least.

(c) Installations: Fixed accessories for installing a camera. In the event of a camera installation, the weight of bombs decreases in proportion.

(d) Instruments: Same as for night bombardment machine less compass.

(e) Bombs: Normal load of bombs, 100 kilograms.

(f) Endurance: Load of oil and gasoline sufficient for a flight of 2 hours and 30 minutes at a speed of 130 kilometers per hour and at an altitude of 500 meters, with machine complete with crew, armament, and bombs.

(g) Maximum velocity: With machine fully loaded and at an altitude of 500 meters the maximum speed must not be less than 140 kilometers per hour.

(h) Minimum velocity: Minimum velocity must not exceed 70 kilometers per hour at 500 meters with a full complement of crew, fuel for 30 minutes' flight, but without bombs.

(i) Climb: Two-thousand-five-hundred meters in not over 30 minutes with machine fully loaded.

(j) Armor: A special armor for protecting the pilot, the machine gunner, the engine, the gasoline and oil tanks and the radiator.

(k) Cellule and fuselage: Elements of the cellule and fuselage must be of metal except wing spars and fuselage longerons.

(l) Coefficient of safety in the static test: The coefficient of safety in the static test with respect to conditions of a full normal load must not be inferior to 7. In every case this test must fulfill the rules prescribed by the Institute of Experimental Aeronautics for carrying out the static tests, due account being taken of the characteristics of the machine.

TACTICAL RECONNAISSANCE MACHINE.

(a) Crew: One pilot, one observer, and one machine gunner. Machine is equipped with dual control.

(b) Armament: One pair Fiat machine guns for rear fire with large firing section and an allowance of 1,000 rounds of ammunition.

(c) Installations: Fixed accessories for radiotelegraphic and radiotelephonic receiving and transmitting plants, and for two cameras; navigating lights; device for illuminating the ground on landing: and interior illumination for reading the instruments.

(d) Instruments: Same as for night bombardment machines.

(e) Endurance: Load of gasoline and oil sufficient for a flight of three hours at a speed of 180 kilometers per hour and at an altitude of 2,000 meters, with machine complete with crew, armament, and installations.

(f) Maximum velocity: With machine fully loaded and at an altitude of 3,000 meters the maximum speed must not be less than 190 kilometers per hour.

(g) Minimum velocity: Minimum velocity must not exceed 90 kilometers per hour with full complement of crew, machine gun with 500 rounds of ammunition, radiotelegraphic and radiotelephonic equipment, photographic machine complete, and fuel for one hour's flight.

(h) Climb: Three thousand meters in not over 20 minutes with machine fully loaded.

(i) Coefficient of safety in the static test: The coefficient of safety in the static test with respect to conditions of a full normal load must not be inferior to 9. In every case this test must fulfill the rules prescribed by the Institute of Experimental Aeronautics for carrying out the static tests, due account being taken of the characteristics of the machine.

STRATEGICAL RECONNAISSANCE MACHINE.

(a) Crew: One pilot and one machine gunner.

(b) Armament: One machine gun for forward fire and one for rear fire.

(c) Installations: Fixed accessories for installing two cameras and for a radiotelegraphic plant.

(d) Instruments: Same as for night bombardment machine.

(e) Endurance: Load of gasoline and oil sufficient for a flight of five hours at a speed of 230 kilometers per hour at an altitude of 3,000 meters, with machine complete with crew, armament, and installations.

(f) Maximum velocity: With machine fully loaded and at an altitude of 3,000 meters the maximum speed must not be less than 250 kilometers per hour.

(g) Minimum velocity: Minimum velocity must not exceed 100 kilometers per hour at 500 meters, with full crew, installations, and armament complete, and fuel for one hour's flight.

(h) Climb: Five thousand meters in not over 30 minutes with machine fully loaded.

(i) Coefficient of safety in the static test: The coefficient of safety in the static test with respect to conditions of a full normal load must not be inferior to 11.5. In every case this test must fulfill the rules prescribed by the Institute of Experimental Aeronautics for carrying out the static tests, due account being taken of the characteristics of the machine.

DAY PURSUIT MACHINE.

(a) Crew: Monoplace machine.

(b) Armament: Two Vickers machine guns for forward fire with an allowance of 1,000 rounds of ammunition.

(c) Installation: Device which permits the flight commander to transmit orders; and one camera.

(d) Endurance: Load of oil and gasoline sufficient for a flight of three hours at a speed of 250 kilometers per hour at an altitude of 4,500 meters with machine complete with crew, armament, and installations. Fireproof tanks.

(e) Instruments: Same as for night bombardment machine, less compass.

(f) Maximum velocity: With machine fully loaded and at an altitude of 2,000 meters the maximum speed must not be less than 270 kilometers per hour.

(g) Minimum velocity: Minimum velocity must not exceed 110 kilometers per hour at 500 meters with full armament and installations, and fuel for 30 minutes' flight.

(h) Climb: Five thousand meters in 15 minutes with machine fully loaded.

(i) Coefficient of safety in static test: The coefficient of safety in the static test with respect to conditions of a full normal load must not be inferior to 12. In every case this test must fulfill the rules prescribed by the Institute of Experimental Aeronautics for carrying out the static tests, due account being taken of the characteristics of the machine.

NIGHT PURSUIT MACHINE.

(a) Crew: Monoplace machine. Visibility must be excellent.

(b) Armament: Two Vickers machine guns for forward fire with an allowance of 1,000 rounds of ammunition.

(c) Installations: Device for illuminating the ground on landing; navigating lights; internal lighting system for reading the instruments.

(d) Exhaust and muffler: A device for hiding the glare of the exhaust; a muffler. The pilot must be able to open up the exhaust when desired.

(e) Instruments: Same as for night bombardment machine, less compass.

(f) Visibility: The pilot's seat must give excellent visibility for the particular employment for which the machine is destined as well as for maneuvering for a landing.

(g) Endurance: Load of oil and gasoline sufficient for a flight of four hours at a speed of 150 kilometers per hour,

and at an altitude of 3,500 meters with machine complete with crew, armament, and installations.

(h) Maximum velocity: With machine fully loaded and at an altitude of 2,000 meters the maximum speed must not be less than 160 kilometers per hour.

(i) Minimum velocity: Minimum velocity must not exceed 60 kilometers per hour at 500 meters with complete armament and installations, and fuel for one hour's flight.

(j) Climb: Five thousand meters in not over 25 minutes with machine fully loaded.

(k) Coefficient of safety in the static test: The coefficient of safety in the static test with respect to conditions of a full normal load must not be inferior to 8. In every case this test must fulfill the rules prescribed by the Institute of Experimental Aeronautics for carrying out the static tests, due account being taken of the characteristics of the machine.

ITALIAN EXPERIMENTAL STATION.

The Italian Experimental Station, under the direction of Colonel Verduzio, is located on the outskirts of Rome. It is a fairly well-equipped station for aeronautical experimental and research work. However, its activities were necessarily curtailed by the financial conditions existing throughout Italy. Comparatively little work was being done, but the subjects which are of greatest interest to Italy were being investigated as far as the available funds would permit.

The Crocco wind tunnel, which is universally known, is housed in this institute. The Crocco tunnel is of the closed circuit type, driven by a 17-bladed wind screw at the rate of 450 revolutions per minute. A 150-horsepower engine is the source of power. This tunnel is sufficiently well known to make further description unnecessary.

The institute also houses three small-scale tunnels which have been constructed for instructional purposes.

The most interesting device for studying air flow was one which was being tried out in an endeavor to be able to actually see the disturbance of air behind a surface. They hope to achieve this by means of a long telescope and an electric spark jumping across a gap. Some degree of success had been achieved, but considerable work remained to be done. This device was carefully inspected, but in its present stage of development does not warrant greater description. Their altitude chamber offered nothing novel.

The Italians, of course, are most interested in lighter-than-air machines and this branch of aviation is receiving the bulk of attention. Exhaustive tests are being conducted on the proper streamlining for dirigible shapes, cars, engine nacelles, surfaces, keels, etc. These are conducted both in the wing tunnel and in the tanks. Right in line with this development, considerable work was being done to determine the strength of fabrics. Tests were being conducted to determine the breaking strength and the ga pressure under which it would fail. Any number ot tests were being conducted to determine the permeability of the fabric by exposure to the weather when the fabric was under constant gas pressure. Other permeability tests were being conducted to determine the effect of the chemicals in the gas on the texture of the fabric and its permeability when subjected to tests under high-powered mercury vapor lamps while withstanding various pressures of gas. This mercury vapor light is supposed to be a more severe test than ordinary sunlight. Any number of methods are being used to determine the amount of leakage of gas through the fabric and the Italians have done a great deal of work in the perfecting of rubberized gas bags.

The usual facilities had been installed for testing metals, and most of the work being done along this line was in conjunction with steel tubes to be used in dirigible frames.

It is interesting to note that most of the experimental work being done with dirigible shapes contemplates both the nose and tail of the ship being constructed with a framework as a part of the flexible keel. All control surfaces were internally braced. The engines were all mounted on outriggers and all fuel was kept out of the main cabin.

Some interesting development work has been done with parachutes, not only of the single-man type but parachutes to drop baskets from kite balloons. There is nothing new or novel about any of their parachutes, but there was a rather clever device to release the parachute from the basket or man as soon as it strikes the ground.

Much attention is being given to seaplane development, and any number of tests were being conducted in a large model basin, 600 meters long by 3 meters wide. A third-rail system handles the model and devices are provided for procuring accurate readings.

Rather interesting results have been obtained with a whirling arm mounted over a tank of water.

One of the most interesting developments of the Italian technical section was the Italian flying bomb, or the "Teleo" bomb, as it was called. This is adequately described in the "Résumé of Italian Aeronautical Activities."

They also had an interesting target airplane which is fully described under the appropriate heading.

The activities of the Italian aeronautical section show that the personnel is working hard and conscientiously to develop new equipment and to improve their present machines, but the lack of financial support is evident and the entire establishment gives the impression of being practically abandoned.

ITALIAN DIRIGIBLE.

Mr. Usuelli has projected a dirigible known as the T–120, of 120,000 cubic meters, the designing of which has practically been completed.

The endurance of the T–120 will exceed 15,000 kilometers. Such an endurance is attainable with the full navigating equipment and a useful load of 100 passengers and relative baggage. The cruising speed will be 90 kilometers per hour, to attain which only one-half of the engine power is used. There is, therefore, a reserve engine power of 100 per cent. It running under full power the airship would have a speed of 120 kilometers per hour. This power is subdivided into eight engine nacelles with double engine and double propeller. The engines are of 250 horsepower. Unlike the dirigible *Roma*, the engine nacelles in the T–120 are suspended by cables; that is to say, they consist of a suspended car of a penetrating form with a rigid bridge and gangway.

The commander's cabin is located in the prow and has a splendid field of visibility. Next to it is the passengers' cabin which is divided by a wide corridor. Armchairs or beds may be easily installed. The nose and stern are rigid. The rudders and elevators which are of monoplane type are fastened to the keel by internal bracing. This tail is markedly superior to the one on the *Roma*.

The keel is triangular.

The airship can be very readily transformed into a war type for bombardment work at great distances. If this was desired, the passengers' cabins could be replaced by a distributed load of 10 tons of bombs or aerial torpedoes. With full war equipment this airship could easily attain an altitude of 5,000 meters.

This ship is the semirigid type with a keel running from bow to stern. Both bow and stern are rigid. Three round, steel tubes are welded into ball-and-socket joints at each end to form the units used to construct the ship. These are then used in lengths of 5 to 10 meters each to form a great triangular keel. Superimposed above this triangular frame are other members which continue the sides of the triangle up to the envelope.

The gas is carried in numerous compartments as is standard practice with semirigids. The envelope is held in shape by air pressure.

With their intimate knowledge of semirigids and their expertness with fabric, the Italian could turn this ship out in a very creditable way and it would be a valuable addition to the aeronautical equipment of any nation.

SAVOIA FLYING BOATS.

The Savoia Co. are the best seaplane and flying boat constructors in Italy. Their interpretation of hull construction evidences marked superiority of design and craftsmanship and entitles them to rank high among the world's best air-boat constructors. Their seaplanes are also very good, and the performances attained with their different models have been comparable with best results attained anywhere.

In their hull construction they employ walnut longerons, ash ribs, and poplar veneer covering. The workmanship is excellent and the care exercised in the detail work is remarkable. Their wings do not differ from other wings in design or construction. However, the fin is built integral with the aft end of the hull and is very thick to provide a good mounting base for the empennage proper.

The tail control countershaft is located in the fin. The entire tail plane, which is generally very wobbly on flying boats, in this case is very rigid. An interesting feature in their tail plane construction is the way the two spars in the stabilizer are supported by one steel tube brace. To the usual steel tube which runs from the fuselage to the rear spar is welded another tube in Y fashion to support the front spars. This provides a rigid brace for both longerons without the necessary addition of a second tube. This idea could be utilized on all planes.

The engine is mounted in such a way that four struts can be removed and then the engine and entire mounting structure removed in short order. The engine mounting is very simple and permits great accessibility to the engine. The gas tanks in all Savoia models are suspended from the engine mounting.

They employ nose radiators in all of their types. The hull bottoms are all concave. Ailerons are provided on the top planes only. Four-bladed propellers of their own manufacture are used. Adequate provision is made everywhere for inspection. In front of the pilot is a single cockpit for the navigator or the gunner. Provision is made to transform their ships into bombers by the addition of bomb racks on the underside of the wings

SAVOIA S-13.

This machine has been adopted for reconnaissance work by the Italian Navy.

The bottom and sides of the boat up to the water line and also the bulkhead are constructed by placing the struts of the engine bed diametrically.

The tail surfaces with internal controls have been located much higher and the bottom of the rudder has been covered with sheet metal to avoid injury in the water.

This machine will have the Hispano-Suiza 300-horsepower engine substituted for its present Isotta power plant.

Spain has recently ordered 12 more of this type, as she has had a great deal of satisfactory service with them in Morocco.

Characteristics of the *S-13* are as follows:

Span: 11.08 meters.
Length: 8.99 meters.
Height: 3.16 meters.
Motor, Hispano-Suiza: 300 horsepower.
Area: 40.60 square meters.
Weight, empty: 1,000 kilograms.
Useful load: 400 kilograms.
Total weight: 1,400 kilograms.
Load per square meter: 34 kilograms.
Velocity: 200 kilometers per hour.
Chord of upper wing: 1.90 meters.
Chord of lower wing: 1.55 meters.
Tail span: 5 meters.
Hull length: 8.49 meters.

SAVOIA S-16 BIS.

This is an improvement over the original *S-16*. The tail surfaces have been raised and the area has been increased. The lower wings have been given lateral dihedral in order to obtain greater lateral stability. Ailerons are fitted to the lower wing only. The attachments of the wing floats to the bottom wing have been simplified and reduced in number so as to cut down head resistance. This machine carries six passengers, including the pilot. It has a range of 600 kilometers. The first of these machines have been purchased by Spain. Characteristics of this type are as follows:

Span: 15.50 meters.
Total length: 9.97 meters.
Total height: 3.67 meters.
Motor, Fiat A-12 bis: 300 horsepower.
Total area: 59.15 square meters.
Weight, empty: 1,700 kilograms.
Useful load: 750 kilograms.
Total weight: 2,450 kilograms.
Load per square meter: 42 kilograms.
Maximum speed: 170 kilometers per hour.
Chord of upper wing: 2.20 meters.
Chord of lower wing: 1.85 meters.
Hull length: 9.39 meters.
Tail span: 3.80 meters.

SAVOIA S-19.

This is the racing type that was especially constructed for the Schneider cup race. It is one of their standard flying boat types equipped with the 450 horsepower Ansaldo-San Giorgio engine. Speed of the machine is 238 kilometers per hour. The company is reserving this type for some future race and it has been impossible to obtain characteristic data on that account.

SAVOIA S-22.

This machine is a twin-motored, tandem job, equipped with two Isotta 250-horsepower engines.

Speed: 225 kilometers per hour.
Ceiling: 6,000 meters.
Endurance: 4 hours.
Total weight: 2,500 kilograms.
Weight, empty: 1,600 kilograms.
Useful load: 900 kilograms.
Span: 13.50 meters.
Length: 10.78 meters.
Height: 3.52 meters.
Coefficient of safety: 8.

SAVOIA S-21.

Speed: 280 kilometers per hour.
Motor, Ansaldo: 300 horsepower.
Ceiling: 5,000 meters.
Endurance: 1½ hours.
Total weight: 900 kilograms.
Weight, empty: 70 kilograms.
Useful load: 200 kilograms.
Span: 7.69 meters.
Length: 7.62 meters.
Height: 2.64 meters.
Coefficient of safety: 11.

This machine is one of the latest speed jobs which they have constructed and tested.

SAVOIA S-23.

Span: 12.440 meters.
Height: 3.230 meters.
Length: 9.990 meters.
Passenger capacity: 2.
Motor, Isotta: 160 horsepower.
Area: 43.39 square meters.
Weight, empty: 1,143.9 kilograms.
Total weight, loaded: 1,385 kilograms.
Load per square meter: 31 kilograms.
Hours of flight: 2½ hours.
Velocity, minimum: 75 kilometers per hour.
Velocity, maximum: 155 kilometers per hour.

This is a type of school machine. It has a supporting area slightly inferior to the *S-13*. It is very strongly built. The boat is covered, as are all the other Savoia types, with veneer planking. The small auxiliary wing floats are of veneer also. Ailerons are fitted to the lower wings only. The tail surfaces are of the raised type and have internal controls. It is equipped with a four-bladed propeller. Its flying qualities have been pronounced very excellent for instructional purposes. It has a marked degree of responsiveness to controls. Twenty-five of these have been purchased by Spain.

SAVOIA S-24.

This machine is constructed along the same lines as the *S-22*, but is much larger and intended principally for civilian use. Two motors are installed in tandem. The machine is of the two-bay wing-truss type and will accommodate approximately 10 to 12 passengers. The first machine has been completed and its speed is 170 kilometers per hour. It is expected to attain a speed of approximately 150 kilometers per hour with one engine. This machine has a biplane tail. The passengers are totally inclosed in the hull, while the pilot and mechanic are placed forward.

Characteristics of this machine are as follows:

Span: 19 meters.
Length, over all: 13.30 meters.
Total height: 4.75 meters.
Motor, Fiat A-12 bis: 300 horsepower.
Total area: 98.75 square meters.
Weight, empty: 2,600 kilograms.
Useful load: 1,600 kilograms.
Total weight: 4,200 kilograms.
Surface load: 43 kilograms per square meter.
Velocity: 170 kilometers per hour.
Chord of upper wing: 2.8 meters.
Chord of lower wing: 2.56 meters.
Span of tail: 4 meters.

The Savoia firm has recently acquired the services of Mr. Marchetti and will construct 12 Marchetti land pursuit airplanes for the Italian Air Service. No examples of this machine have been constructed other than the two officially tested out by the Army Air Service in 1919. This machine was credited with a speed of 270 kilometers per hour.

MACCHI SEAPLANES.

The Macchi Co. is one of the most expert seaplane construction companies in the world. The design, craftsmanship, and performance of their product are excellent.

The engineers of the Macchi Co. are now studying a new, bimotored, torpedo-carrying seaplane for the Italian Navy. No definite information could be secured in reference to this model other than it would have the conventional Warren wing truss used by the Macchi Co., and the parabolic, concave V bottom that characterizes all their machines. The motor mount will be of the truss type and it will have a nose radiator.

Their last new machine was the *Macchi 19*, or *M-19*, as it is familiarly called. This was a biplane seaplane powered with a 700 Fiat motor.

The Macchi Seaplane Co. has a very interesting little, two-seater sport type seaplane, powered with a three-cylinder Anzani engine of 30 horsepower.

The total area is: 11.3 square meters.
Weight, empty: 160 kilograms.
Useful load: 100 kilograms.
Total weight: 260 kilograms.

The useful load is made up of:

Pilot: 70 kilograms.
Fuel: 30 kilograms.
Span: 6 meters.
Length: 4.22 meters.
Height: 2.12 meters.
Velocity, maximum: 130 kilometers per hour.

Landing speed: 4 kilometers per hour.
Load factor of safety: 12.
Range: 420 kilometers.
Climb to 1.000 meters: 9 minutes.
Climb to 2.000 meters: 22 minutes 40 seconds.
Climb to 3.000 meters: 40 minutes 45 seconds.
Climb to 4.000 meters: 1 hour 30 minutes.

The Macchi Co. is building quite a number of these machines for distribution to the Italian squadrons for acrobatic and practice flying work.

Our Navy has recently purchased some of this type, which are at Anacostia. It is claimed that this type is very economical for keeping the pilots in flying trim.

The Macchi Co. is very well equipped to carry out flying boat construction and is specially noted for their hull construction. They are now constructing a number of *M-18* school flying boat type machines for the Italian Navy.

Characteristics of this machine are as follows:
Span: 15.80 meters.
Length: 9.75 meters.
Total height: 3.25 meters.
Motor, 6-cylinder Isotta: 250 horsepower.
Area: 45 square meters.
Weight, empty: 1.000 kilograms.
Useful load: 250 kilograms.
Total weight: 1.250 kilograms.

The useful load is made up as follows:
Pilot and student: 150 kilograms.
Fuel, 2½ hours: 95 kilograms.
Instruments: 5 kilograms.
Factor of safety: 10.
Maximum velocity: 160 kilometers per hour.
Minimum speed: 80 kilometers per hour.
Range: 350 kilometers.

MACCHI—M—15.

The Italian Army Air Service has recently ordered from the Macchi firm 12 M 15 two-place land machines for reconnaissance purposes. This is of the single-fuselage type, nose radiator, powered with Fiat A-12 bis, 300-horsepower engine, and with Warren truss wings.

Characteristics of this machine are as follows:
Span: 13.475 meters.
Length, over all: 8.570 meters.
Height: 3.300 meters.
Area: 42 square meters.
Weight, empty: 1.125 kilograms.
Useful load: 510 kilograms.
Total weight: 1.635 kilograms.

Load is made up as follows:
Pilot and observer: 150 kilograms.
Fuel for three hours: 225 kilograms.
Three machine guns: 45 kilograms.
Ammunition: 25 kilograms.
Photographic apparatus: 35 kilograms.
Radio and electrical installation: 25 kilograms.
Instruments: 5 kilograms.
Velocity: 200 kilometers per hour.
Factor of safety: 9.
Range: 600 kilometers.
Climb to 1.000 meters: 4 minutes, 40 seconds.
Climb to 2.000 meters: 10 minutes 45, seconds.
Climb to 3.000 meters: 19 minutes.
Climb to 4.000 meters: 30 minutes, 30 seconds.
Climb to 5.000 meters: 50 minutes.

This machine has not been executed in up-to-date fashion and does not represent the last word in construction. Accessibility, maintenance, and replacements on this type have not been very well thought out.

The Macchi firm has recently sold four of their old M-7 machines to Sweden.

THE ITALIAN SEAPLANE P. R. B. 1.

One of the most interesting seaplanes designed and built in Italy, representing a departure from the conventional, was the P. R. B. 1. It was designed by Mr. Pegna. It is a four-motored machine employing the Fiat 300-horsepower engine.

Principal characteristics are as follows:
Span: 3.40 meters.
Chord: 3.50 meters.
Gap: 4 meters.
Tail surface: 18 square meters.
Mobile surface: 6 square meters.
Total height: 6.60 meters.
Total length: 18 meters.
Width of hull, maximum: 2.81 meters.
Height of hull, maximum: 2.60 meters.
Length of wing floats: 3.50 meters.
Width of wing floats: 0.70 meter.
Height of wing floats: 0.70 meter.
Weight, empty: 5.200 kilograms.
Total weight: 8.200 kilograms.
Useful load: 3.000 kilograms.
Total horsepower: 1.040.
Weight per horsepower: 7.88 kilograms.
Weight per square meter: 39.61 kilograms.
Maximum speed, fully loaded: 170 kilometers per hour.
Economical speed: 150 kilometers per hour.
Landing speed: 80 kilometers per hour.

This machine is featured by its tandem Fiat engines mounted on the lower wing. They permit ready accessibility during flight or while on the water and the installation has permitted considerable cleaning up of the wings. It has none of the conventional type of supermotor structure.

The boat hull is constructed entirely of veneer with the usual concave bottom. The horizontal surfaces are adjustable during flight. Very close attention has been given in this job to streamlining wherever possible. Even the wire terminal fittings and fastenings are streamlined. Photographs of this machine are available at McCook Field.

This machine has considerable weight, but according to the designer it can be lightened in future jobs. It would be very well adapted for the installation of four Liberties without any appreciable increase in power plant weight inasmuch as the Fiat A-12, 300-horsepower engines weigh approximately the same as the Liberty 12 with 100 horsepower less.

This is the only four-motored seaplane built in Italy to date.

According to Mr. Pegna, setting the motors low on the wing did not give any trouble from water being sucked

up into the propeller zone, owing to the peculiar concave shape of the bottom of the boat. A chine guard base has been added, being attached on the bottom of the hull along the chine so as to neutralize as much as possible the chine wave spume. This spume is always evident with the V bottom type hulls.

The hull is entirely devoid of bulkhead construction and the internal bracing is effected by the addition of steel tubing. The bottom bracing from the step forward is of wood pieces, employing the Pratt truss. The ends of the rib stations use wires for their bracing.

The gasoline tanks are located on the upper wing. This is a radical departure from ordinary seaplane fuel tank adaptations and it minimizes the fire hazard to a marked degree.

The interpretation of this machine as a whole is a departure from the conventional with distinct advantages. The streamlining, accessibility, and very economical power plant mounting are commendable. The detail construction in the hull is to be criticized, but as a whole the general outlines and general arrangement of the machine are excellent.

FIAT PLANES AND MOTORS.

The Fiat Co. was one of the companies in Italy that had a huge amount of war stock on hand at the cessation of hostilities. They have attempted to dispose of this material to the best advantage and do a little development work at the same time. Their most interesting motors and machines are described below.

FIAT ENGINE TYPE A 12 BIS.

The characteristics of the famous Fiat A 12 bis, six-cylinder engine are as follows:

Power, maximum, at 1,700 revolutions per minute: 340 horsepower.
Power, average, at 1,600 revolutions per minute: 304 horsepower.
Power, guaranteed, at 1,600 revolutions per minute: 265 horsepower.
Normal speed: 1,700 revolutions per minute.
Maximum speed: 1,800 revolutions per minute.
Average speed of piston: 9.6 meters per second.
Number of cylinders: 6.
Cylinder bore: 160 millimeters.
Stroke: 180 millimeters.
Ratio of compression $\frac{V+v}{v}$: 4.7.
Average pressure: 7.6 eff. atmospheres.
Total weight, empty: 385 kilograms.
Total weight including water: 400 kilograms.
Approximative total weight with water and radiator: 442 kilograms.
Weight per horsepower with engine empty: 1.15 kilograms.
Weight per horsepower with water and radiator: 1.30 kilograms.
Petrol consumption per horsepower hour—
Guaranteed: 0.235 kilogram.
Average: 0.220 kilogram.
Oil consumption per horsepower hour—
Guaranteed: 0.025 kilogram.
Average: 0.015 kilogram.
Lubrication system: Forced feed.
Ignition system: 2 magnetos with 6 spark plugs.
Number of spark plugs for each cylinder: 2.
Number of valves per cylinder: 4.
Number of carburetors: 4.

Remarks.—The weights are to be allowed 5 per cent plus tolerance. The propeller is applied directly on the crank shaft with left-handed rotation and may be either tractor or pusher.

Further discussion of this engine is not necessary, as it is an old type and abundance of information is in our files.

FIAT A 14.

This motor is the famous 700-horsepower 12-cylinder Fiat engine which has been used with their B. R. and A. R. F. types of planes as well as their large passenger-carrying model. It is also used in the Fiat racer that Brack Papa flew in the French airplane cup race last year.

Power, maximum, at 1,700 revolutions per minute: 750 horsepower.
Power, average, at 1,650 revolutions per minute: 685 horsepower.
Power, guaranteed, at 1,650 revolutions per minute: 625 horsepower.
Normal speed: 1,650 revolutions per minute.
Maximum speed: 1,700 revolutions per minute.
Average speed of piston: 10.8 meters per second.
Number of cylinders: 12.
Stroke: 210 millimeters.
Cylinder bore: 170 millimeters.
Ratio of compressions $\frac{V+v}{v}$: 4.5.
Average pressure: 6.7 eff. atmospheres.
Total weight when empty: 730 kilograms.
Total weight including water: 760 kilograms.
Approximative total weight with water and radiator: 845 kilograms.
Weight per horsepower with engine empty: 0.970 kilogram.
Weight per horsepower with water and radiator: 1.13 kilograms.
Petrol consumption per horsepower hour—
Guaranteed: 0.235 kilogram.
Average: 0.220 kilogram.
Oil consumption per horsepower hour—
Guaranteed: 0.030 kilogram.
Average: 0.022 kilogram.
Lubrication system: forced feed.
Ignition system: 4 magnetos with 12 spark plugs.
Number of spark plugs for each cylinder: 4.
Number of valves per cylinder: 4.
Number of carburetors: 4.

Remarks.—The weights are to be allowed 5 per cent plus tolerance. The propeller is applied directly on the crank shaft with left-handed rotation and may be either tractor or pusher.

FIAT ENGINE A 15 R.

Fiat engine A 15 R. 400 horsepower, 12-cylinder, is of the geared-down type and is apparently very clean in appearance. Photographs of this motor will be found in our files.

Characteristics of this motor are as follows:

Power, normal: 400 horsepower.

Power, maximum: 425 horsepower.

Propeller, normal speed: 1,500 revolutions per minute.

Number of cylinders: 12.

Cylinder bore: 120 millimeters.

Stroke: 150 millimeters.

Ratio of compression, $\frac{V+v}{v}$: 5.5.

Average pressure: 7.7.
(Eff. atm. kg/cm.^{2}.)

Total weight when empty: 365 kilograms.

Total weight including water: 385 kilograms.

Approximative total weight with water and radiator: 410 kilograms.

Weight per horsepower with engine empty: 0.9 kilogram.

Weight per horsepower with water and radiator: 1.005 kilograms.

Petrol consumption per horsepower hour—
Guaranteed: 0.240 kilogram.
Average: 0.220 kilogram.

Oil consumption per horsepower hour—
Guaranteed: 0.025 kilogram.
Average: 0.012 kilogram.

Lubrication system: Forced feed.

Ignition system: 2 magnetos with 12 spark plugs.

Number of spark plugs per cylinder: 2.

Number of valves per cylinder: 4.

Number of carburetors: 4.

Remarks.—The weights are to be considered with 5 per cent plus tolerance. The propeller is applied on the speed-reducer shaft and its reduction ratio with the crank shaft is of 1:1.51.

The propeller rotation is left-handed and the propeller may be a tractor or a pusher.

The propeller shaft is drilled with with a hole 58 millimeters in diameter, through which can be fired a machine gun or cannon.

FIAT ENGINE A 18.

The Fiat engine A 18, 200 horsepower, nine-cylinder, water-cooled type, has the following characteristics:

Power, maximum, at 2,000 revolutions per minute: 320 horsepower.

Power, average, at 1,800 revolutions per minute: 300 horsepower.

Power, guaranteed, at 1,800 revolutions per minute: 300 horsepower.

Normal speed: 1,800 revolutions per minute.

Maximum speed: 2,000 revolutions per minute.

Cylinder bore: 130 millimeters.

Total weight when empty: 230 kilograms.

Average speed of piston: 9 meters per second.

Stroke: 150 millimeters.

Ratio of compression $\frac{V+v}{v}$: 5.5.

Average pressure: 7.7 eff/atmospheres.

Total weight including water: 248 kilograms.

Approximative total weight with water and radiator: 285 kilograms.

Weight per horsepower with engine empty: 0.72 kilogram.

Weight per horsepower, engine with water and radiator: 0.89 kilogram.

Petrol consumption per horsepower hour—
Guaranteed: 0.240 kilogram.
Average: 0.220 kilogram.

Oil consumption per horsepower hour—
Guaranteed: 0.030 kilogram.
Average: 0.020 kilogram.

Lubrication system: Forced feed.

Ignition system: 2 magnetos with 9 spark plugs.

Number of spark plugs for each cylinder: 2.

Number of valves per cylinder: 4.

Number of carburetors: 1.

Remarks.—The weights are to be allowed 5 per cent plus tolerance. The propeller is applied directly on the crank shaft with left-handed rotation and may be either tractor or pusher.

FIAT B. R.

This machine has the static factor of safety of 9, with an inclination of 25 per cent and with dissymmetric alternate loadings by 1 factor.

Characteristics are as follows:

Total weight of machine: 2,300 kilograms.

Useful load, including pilot, observer, armament, bombs, gas and oil: 1,000 kilograms.
(Although 1,200 kilograms have been carried.)

Total weight: 3,300 kilograms.

Normal load—
Equipment: 150 kilograms.
Armament: 45 kilograms.
Fuel for 3½ hours' flight, made up of—
Oil: 60 kilograms.
Gas: 370 kilograms.
Bombs: 370 kilograms.

Performance with useful load of 1,000 kilograms—
Speed at sea level: 253 kilometers per hour.
Speed at 1,000 meters: 245 kilometers per hour.
Speed at 2,000 meters: 241 kilometers per hour.
(The maximum speed attained by this machine at sea level has been up to 270 kilometers per hour; minimum, 99 kilometers per hour.)

Span of wings: 15.500 meters.

Total length: 9.820 meters.

Height: 3.800 meters.

Chord: 2.35 meters.

The B. R. is a monomotored plane with fuselage and cellule biplane semirigid. It was designed about the time the war ended for rapid, long-distance, day bombardment work. This machine, which has been used for many months by the Italians, has a static resistance and characteristics of flight which are remarkable.

Wing foil.—The lower left wing, in comparison with the right, is longer in order to correct the torque produced by the motor during flight.

(The transversal V for lateral stability is 2°.)

The upper planes are provided with compensated ailerons.

The gravity tank is placed in the center section. The mounting of the wings is of the semirigid type, with rigid uprights in the part nearest the fuselage and diagonals and counter-diagonal braces in the outer sections only. The wings are of conventional stick and wire construction.

Fuselage.—The fuselage has a mixed structure of wood (longerons, uprights, crosspieces) and steel (outer supports, motor support, foot supports, etc.). The covering is of wood veneer except the lower part, which is covered with linen. The section is almost entirely rectangular. The forward part of the longerons are of oak, the back part of spruce.

The motor supports are of soft sheet steel.

The disposition which is successively encountered is: Propeller, radiator, motor, under which is placed the oil-tank furnished with a radiator situated below the lower surface of the fuselage, vertical bomb rack, pressure gas tanks, pilots' seat, observer's seat furnished with a machine gun for firing toward the rear, bottle of compressed air for starting the motor, and the empennage.

Empennage.—The empennage comprises a fixed fin, a horizontal stabilizer, fixed, and a compensated rudder and elevator. All the structure of the empennage is of wood with the exception of the bearing axes, the hinges, and the control levers.

Motor apparatus.—The motor apparatus comprises: One aviation motor, Fiat A-14, 700 horsepower, 1,650 revolutions per minute.

Bomb rack.—The airplane is furnished with two bomb racks, a vertical one in the fuselage with a capacity of three bombs, 280 millimeters, 25 kilograms each; and a bomb rack placed upon the lower wing for six "Batignolle" bombs, three on each side of the fuselage.

FIAT C. R.

The Fiat Co. has recently laid out a new single-seater pursuit airplane around the 300 horsepower engine. This machine has the Warren truss type wing structure that is ordinarily characteristic of most Italian jobs. The fuselage construction is practically the same as the BR, which has been described.

This machine is equipped with a nose radiator. It has not been built to date, but the Fiat Co. hopes to build it very soon for the Italian Air Service, which has on hand 2,000 300-horsepower Hispano engines which they intend to use very shortly in their new program in equipping all their future pursuit planes. The description of this machine is as follows:

Manufacturers' description—cellule.—The cellule is biplane and the two surface planes are joined together by an entirely rigid structure which assures a high static resistance, indeformability, and a lower head resistance than that obtained with other cellules of ordinary type.

Because of the special system of rigid mounting adopted, the lower wing is longer than the upper. The ailerons are actuated by a rigid tube control. Little universal joints are applied in the control tube in order to render control easier even during acrobatic evolutions.

The longer lower wing has also the advantage of lowering the center of gravity of the machine, bringing it nearer to the center of surface pressure (generally high), in a manner which assures easy guidance of the machine in all directions. It seems, besides, that the longer lower wing assures a better control in flights near the ground, which naturally facilitates landing.

The triangular Warren trusswork adopted is an advantage in not being subjected to initial tensions of any sort, and it is unaffected by variations of temperature for its predetermined gap incidence, etc. This characteristic is important in consideration of the considerable discrepancy caused by these variations at the high altitudes at which pursuit planes operate. The completely rigid system, once well regulated, eliminates the series of continual revisions exacted by cellules with diagonals.

Disassembly and assembly of the cellule are also easier. The focusing of the incidence of the surface planes for lateral equilibrium is possible by means of transversal crosspieces among the extreme uprights, and variations of incidence are generally small and can be obtained without the use of special attachments at the ends of the struts. Both top and lower planes have 1° dihedral.

With regard to construction material, they have preserved the old tradition of the mixed system, which still seems to respond to fundamental demands of economy, lightness, resistance, lasting qualities, and ease of construction.

Fuselage and accessories.—The fuselage also has a mixed construction of wood (longerons, uprights, etc.) and metal (diagonals, fitting plates, motor mounting, different installations, etc.). The covering is of veneer wood construction. The maximum length of the fuselage from the outer face of the radiator to the extremity of the tail is about 5 meters, while the maximum width in the principal sections is about 85 centimeters.

In the forward part of the fuselage is the motor mounting made of sheet-steel supports to facilitate easy mounting and demounting of the motor.

The machine is furnished with an oil radiator automatically controlled.

The two machine guns are placed between the two vees of cylinders of the motor and have a mechanical synchronization gear. Their proximity to the pilot assures easy maneuverability of the lever which controls the extractor.

The wind shield is placed so as to render aiming of the guns comfortable for the pilot and assures him perfect visibility either for combat or for landing.

The gas tank (for the time being a pressure tank), placed beneath the pilot, is provided with an ample release mechanism controlled by the pilot, which permits him to free himself of gasoline very rapidly in case of fire.

They have begun the study of a landing gear with steel springs and they hope that it will be superior to the ordinary "sandow" suspensions.

Control surfaces.—They have, with the application of the ailerons in the lower wings, realized the end of having all the control surfaces easy to be inspected even in the most delicate parts of the hinges.

The rigid control obtained for the ailerons obviates the use of cables. For the elevating planes and the rudder, cable controls are provided.

Motor.—The motor applied in this airplane is the Hispano-Suiza 300 horsepower.

Static characteristics.—The coefficient of safety of the machine, in hardest conditions with a load, is about 12½, a figure estimated to be more than sufficient for the most perilous conditions conciliable with the physical resistance of the pilot.

This coefficient has been calculated with a latitude of 2 coefficients more than would be necessary for the absolute safety of the pursuit airplane.

Characteristics:

Weight of airplane, empty: 740 kilograms.
(Gas, 150 kilograms.)
Useful load: 310 kilograms.
(Oil, 25 kilograms; pilot, 75 kilograms; arms, 60 kilograms.)
Weight of plane, fully loaded: 1,050 kilograms.
Maximum wing span: 8.85 meters.
Maximum length: 5.75 meters.
Height: 2.45 meters.
Chord: 1.45 meters.
Plane surface: 22 square meters.
Load per square meter: 47.7 kilograms.
Weight per horsepower: 3.5 kilograms.
Horsepower per square meter: 13.6.
Motor, Hispano-Suiza: 300 horsepower.

Estimated performance characteristics are as follows:

Speed at ground: 270 kilometers per hour.
Speed at 5,000 meters: 260 kilometers per hour.
Climb to 5,000 meters: 15 minutes.
Climb to 6,000 meters: 22 minutes.
Climb to 7,000 meters: 32 minutes.

FIAT RACER.

The Fiat racer is powered with a 700-horsepower Fiat engine.

From all outward appearances it is very conventional in layout and is of the characteristic Fiat type of construction. The only marked departure lies in the radiator installation, which is of the vertical fin type and extends out from the fuselage in the trailing edge of the lower wing.

This machine holds a record of speed on a 100-kilometer course.

The exhaust pipes are so constructed as to give them the least resistance in flight possible. The load factor of safety for the wings is 15. The gasoline tank is located between the pilot and the engine and carries sufficient gas for one and one-half hours' flight.

The tail planes are along the same lines as in the B. R.

The load per square meter is approximately 65 kilograms.

This machine attained a velocity of 299 kilometers per hour when flying over the circuit in the race in France.

The company is now completing two other machines of this type and states that they intend to develop a new type of reconnaissance plane and equip it with an A 12 bis, 300-horsepower Fiat engine.

Factor of safety: 12.
Twenty-five per cent inclination with C. P. 31 to 40 per cent of chord.
Area: 33 square meters.
Diameter of propeller: 3.30 meters.
Total weight: 2,150 kilograms.
Load per square meter: 62 kilograms.
Pitch: 3.40 meters.
Load per horsepower: 3.10 kilograms.
Revolutions per minute: 1,500.

FIAT A. R. S.

The Fiat Co. has designed a two-seater pursuit plane with a 300-horsepower Hispano engine. It has the conventional Fiat wing and truss, nose radiator installation, and characteristic Fiat detailed construction throughout. The upper wing, however, is shorter than the lower wing, and ailerons are fitted to the bottom wings only. The pilot is seated between the two wings and directly beneath the upper wing. This makes the visibility overhead very bad. The gasoline tank is situated underneath the pilot.

This machine was designed to fulfill the specifications for a two-seater fighter as prescribed in the Italian program.

FIAT A. R. F.

Characteristics are as follows:

Total weight: 4,700 kilograms.
Weight, empty: 2,350 kilograms.
Useful load: 200 kilograms.
Gas: 1,850 kilograms.
Oil: 300 kilograms.
Span of wings: 16.23 meters.
Length: 10.126 meters.
Height: 3.700 meters.
Speed: 250 kilometers per hour.
Flight endurance: 18 hours.
Motor, Fiat: 700 horsepower.

This machine is practically a modification of the famous Fiat B. R. and was made for trans-Atlantic flight or for long-distance flight of any nature up to about 18 hours. This machine is very sturdy and is characterized principally by its robust structure in its entirety.

The ailerons have the paddle counterbalancing feature. The fuselage is of the veneer and wire truss type of construction.

FIAT TWELVE-PASSENGER AIRPLANE.

The Fiat Co. has also designed and constructed another interesting type for carrying passengers. It is known as the Fiat 12-passenger airplane. This machine has been fully described in periodicals and complete description was procured for our engineering division.

It is geometrically similar to the Fiat B. R. in its principal outlying characteristics and detailed design. It has the following dimensions and characteristics:

Weight, empty: 3,200 kilograms.
Fuel and oil: 750 kilograms.
Instruments and wireless equipment: 50 kilograms.
Personnel: 150 kilograms.
Total weight: 5,000 kilograms.
Passengers: 850 kilograms.
Motor: 700 horsepower.
Surface area: 125 square meters.
Factor of safety: 8.
Normal flight endurance: 6 hours.
Maximum flight endurance: 6 hours.

FIAT AUTOMATIC CANNON.

Diameter, 25 millimeters.

Complete description of this 26-millimeter cannon is set forth in the Fiat descriptive catalogue which has been mailed to the Air Service Engineering Division.

It is now undergoing exhaustive tests by the Italian Air Service.

Characteristics:

Weight of gun: 45 kilograms.
Weight of projectile: 200 grams.
Weight of charge: 12.5 grams.
Initial velocity: 440 meters per second.
(At mouth of gun.)
Pressure in breech: 2,000 atmospheres.
Rate of fire: 8 rounds per 2 seconds.
Maximum range: 4,000 meters.
Weight of shell container, empty: 1.85 kilograms.
Weight of shell container, full: 4.45 kilograms.

THE CAPRONI CO.

The Caproni Co. is probably the best known aeronautical company in Italy. Mr. Caproni, the head of the firm, is the chief designer as well as the owner of the entire plant. The Caproni factory is located at Taliedo, about 3½ miles out of Milan. It has excellent connections with the city by both steam and electric lines. The plant is large and well equipped for the production of airplanes in great quantities. However, at the present time no work is being done on airplanes and the entire energy of the plant is being devoted to the manufacture of railway cars.

The Caproni Co. has suffered severe financial losses since the war due to the sharp curtailment of orders that were on hand, the failure of the great tandem triplane, and the seizure of the factory by Bolsheviks. During the last winter the shortage of electrical power, caused by the failure of ample rainfall in the Alps, forced rationing of current, and the Caproni plant could operate only three days in the week, and this has tended to further cripple Caproni.

However, he has gone steadily ahead with his work and has design for three new types. He desires to construct a new seaplane and a new airplane, each equipped with four engines, and to again try out his great tandem triplane seaplane.

The Caproni triplane seaplane which failed was one of the most daring attempts ever made in aeronautics. Mr. Caproni carried out extensive experiments with this new tandem triplane at a cost of 3,500,000 lire. This represented practically his entire fortune. Interest in aviation had lagged to such an extent that an ordinary success would not have been sufficient to put him on his feet, so he determined on this radical venture, feeling assured that if he succeeded in flying the triplane and in carrying a tremendous load that it would be sufficient to open a new era in type construction. He believed that he could utilize the planes that had been built for his triplanes during the war and intended to stagger them in such a way that the air flow from the leading planes could be utilized to generate lift under the lower surfaces of the planes behind.

His experimental work was necessarily more or less meager and slipshod, inasmuch as the greatest secrecy was maintained and the officials of the Italian Experimental Station could not be called in without divulging the nature of the work. He was so sure of success that he continued without governmental assistance until the machine was almost completed.

His system of controls, position of planes, methods of construction, and many other features appeared to be quite sound and the machine actually flew. Mr. Caproni attributes the loss of the machine to the inability of the pilot to understand the principles of the moment of inertia. The engine was stalled and the machine dropped into the water with terrific force, breaking the hull. Mr. Caproni believes that had the plane been left where it was that there were sufficient air-tight compartments to sustain it until repairs could be made, but the pilot attempted to taxi the machine, which forced water into the hull, causing the plane to sink, which damaged it to such an extent that repairs were impossible.

Mr. Caproni still believes that the theory of this type of construction is correct, and he intends to go ahead and construct another plane of the same type, which will be much smaller. He intends this to be able to carry about 50 tons. He is receiving some financial assistance from the Italian Government, and it is hoped that he may be able to carry out these experiments in order to determine the relative value of this idea.

The Caproni Co. has transformed a considerable number of their old triplanes into transports. These are all more or less mediocre, of the old conventional orthodox construction. Caproni does not seem to be able to depart from the stick and wood construction with its incident head resistance. However, he is gradually cleaning up his machines.

He has designed a new three-motored machine with twin fuselages and center nacelle. The motor mountings are quite similar to his previous types. This machine has a wide track landing gear very similar to the gear on the American Martins. There is nothing remarkable about the machine, but it is indicative of a slight change in the Caproni types. It is interesting to note that Mr. Caproni built the first successful bimotored ships and has continued to build them almost identical with his first job up to the present day, while his competitors have usurped his ideas and have developed them far beyond anything conceived by Caproni.

The characteristics of his new machines are:

Total weight: 4,100 kilograms.
Useful load: 1,800 kilograms.
Speed: 100 meters per hour.
Ceiling: 3,000 meters.
Power, Isottas: 380 horsepower.
Fuel for four hours.
Crew: 3 men.
Load: 1 ton of bombs.

Three view drawings of this latest machine have been forwarded to the engineering division. This machine is also being studied with a view to equipping it with 300-horsepower engines, and it is quite probable that a small number of these ships will be ordered by the Italian Government for night bombardment work.

To summarize the work of Caproni, one can state that he is still adhering to his stick and wire construction. His ships still have the great head resistance incidental to his type of plane and have no departures in design or in performance. His one possible contribution at the present time may be with the tandem triplane. Not much hope is held out for a sensational success with this particular machine, but it may be the means of procuring a great deal of valuable information as to the utilization of the energy in disturbed air.

THE ANSALDO COMPANY.

The Ansaldo Co. is one of the most active aeronautical concerns in Italy. They are busy constructing several machines for Italy and have negotiated good foreign sales which are directly in line with their desires to build not only for military purposes but to establish commercial markets as well.

Machines of the A-300 C type and of the Balilla type have been sold to Belgium. Spain has purchased 30 of the A-300 type for reconnaissance work and training. Spain is also negotiating at the present time for the purchase of some of the Balilla type. Rumania and Poland have bought some of the A-300 type. Some of the South American Republics, including Ecuador and Peru, are negotiating for some of the S. V. A. and A-300 type.

New types are constantly being constructed by this company, the object being to increase the ultimate performance and the weight carrying per horsepower, but utilizing for the present part of the large stock of left-over war motors of the Fiat, Isotta, and Spa types.

Ansaldo A 300-4.

The most notable Italian military type is the Ansaldo A 300-4 type. This machine is a biplane with a 300-horsepower Fiat engine. The fuselage is entirely constructed of wood with spruce longerons and veneer covering and has a triangular aft fuselage section.

The wings are of the two-bay type. The wing spars are built of two longerons, box-shaped type, covered with linen. The upper wing is fastened to the body by a W-shaped set of center section struts.

The landing gear is entirely of metal with rubber shock absorbers.

The armament consists of two machines guns which are synchronized to the motor, and one movable gun on the observer's tourelle.

The cooling system is of the French Lamblin type.

Characteristics of this machine are as follows:

Over-all length: 8.60 meters.
Height: 2.980 meters.
Span: 11.640 meters.
Total area: 41 square meters.
Load per square meter: 40.800 kilograms.
Load per horsepower: 5.58 kilograms.
Fiat motor, A 12 bis: 300 horsepower.
Weight, empty: 1,225 kilograms.
Useful load: 450 kilograms.
Military load: 150 kilograms.
Total weight: 1,825 kilograms.

The load is made up as follows:

Pilot: 75 kilograms.
Observer: 75 kilograms.
Instruments: 10 kilograms.
Photographic apparatus: 25 kilograms.
Machine gun: 30 kilograms.
Cartridges: 10 kilograms.
Gasoline: 245 kilograms.
Oil: 30 kilograms.
Bombs: 100 kilograms.
Total useful load: 600 kilograms.
Speed at sea level: 200 kilometers per hour.
Speed at 1,000 meters: 195 kilometers per hour.
Climb to 1,000 meters: 7 minutes 20 seconds.
Climb to 2,000 meters: 10 minutes 20 seconds.
Climb to 3,000 meters: 17 minutes 55 seconds.
Climb to 4,000 meters: 26 minutes 10 seconds.
Climb to 5,000 meters: 37 minutes 41 seconds.
Ceiling: 7,000 meters.
Load factor of safety of the wings: 8½.
Load factor of the fuselage: 15.

This machine with the Fiat two-place job represents the best existing Italian two-seaters, and the main reason the performance is not remarkable is that the Fiat engine is very heavy and underpowered for its weight. This machine would have a remarkable performance if it had a power plant installation analogous to our Liberty 12.

ANSALDO SCHOOL MACHINE.

The Ansaldo Co. is completing the construction of a school airplane. The upper and lower wings have the same dimensions. There are ailerons on the lower wings only, as in the A-200 and the A-250 types. The wings and struts are interchangeable. The landing gear is the usual S. V. A. type, but much stronger. It is being equipped with a Colombo 110-horsepower engine. This motor is very heavy, weighing approximately 3 pounds per horsepower.

The radiator, of the Lamblin type, is capable of being shuttered in flight and placed in the undercarriage struts. This machine is fitted with dual control. The fuselage is of the conventional stick and wire construction.

ANSALDO A-200 AIRPLANE.

This is a single-seater and was especially constructed for the races at Brescia. The secondary purpose was to experiment with a new type pursuit airplane. Due to the lack of time before the races, an S. V. A. fuselage was used. Tail surfaces were slightly changed and were similar to the Balilla type. The undercarriage is that of the S. V. A.

Total supporting surface of 15 square meters with a load of 59 kilograms per square meter. The engine is a normal 200-horsepower S. V. A. High speed is 249 kilometers per hour. Ailerons are on the bottom wing. A special fuselage is being built for this machine at present, and when completed this machine will be turned over to the air service experimental section for tests.

ANSALDO 250-HORSEPOWER, A-250 AIRPLANE.

This machine is similar to the A-200 except that it has a slightly increased supporting area and is equipped with an Isotta six-cylinder, 250-horsepower engine. High speed is 248 kilometers per hour.

THE BREDA CO.

The Breda Co. has a wonderful plane located in the outskirts of Milan. This company is perhaps one of the most wonderful manufacturing industries in Italy. They produce everything that can be made from metal. Their principal production at the present time is electric locomotives. The Breda Co. is the General Electric Co. of Italy.

During the war they turned their attention to aeronautics and established a division of their company to produce

aircraft. Their principal work during this period was the construction of Caproni planes. They succeeded in cleaning up the Caproni and reduced the head resistance to a great extent, but the machine was still the Caproni type and the Breda Co. made no radical departures from the conventional design.

A large force of Austrian prisoners were impressed into the service of the Breda Co. and were forced to construct a really wonderful airdrome. Twelve large, roomy, well-lighted concrete and steel hangers were constructed in two groups of six each. The airdrome in front of these hangars is as smooth as a carpet and large enough for any experimental work they may choose to do.

At the time of inspection these hangars were practically empty. A certain amount of aeronautical equipment was being stored for the Italian Government. This consisted mostly of motors.

The Breda Co. is attempting to hold their little aeronautical nucleus together, although they have no substantial orders at the present time to warrant expenditures. Their aeronautical engineers do not appear to be particularly talented. Nothing apart from the conventional was found in their factory. About four different designs of sporting types of planes were being constructed and tested. These were all very small, using rotary engines from 160 to 220 horsepower.

They had converted a Caproni plane into a transport, but the improvements were not sufficient to warrant its production. They have committed the usual error of putting part of the passenger compartment ahead of the motors and leaving the gas tanks inside. This type of construction will never do for transport work as it is not conducive to the safety of the passengers in case of a crash.

The Breda Co. reports that they are constructing a new six-cylinder radial engine. It is supposed to develop 100 horsepower and to weigh approximately 250 pounds. Characteristic data on this motor could not be obtained. They also report that they are working on a 300-horsepower engine and have orders to construct several of these for official test in the near future. The principal improvements claimed for this 300-horsepower motor are that it will be lighter than the Fiat 300 A 12 type and will have a smaller fuel consumption.

The Breda Co. has done some experimental work with the problem of gearing two motors to a single propeller. No reliable information could be obtained, but according to their claims it has undergone successful tests which will warrant continuing its development.

The Breda firm as it stands to-day is not particularly interesting from an aeronautical viewpoint, but is a powerful, potential factor should necessity arise requiring rapid production of aircraft in Italy. Such facilities as are available and the trained force on hand would enable the Breda Co. to quickly expand and turn out large numbers of aircraft.

TARGET AIRPLANE.

The Italians have designed a very interesting and very practicable target airplane that can be constructed at a small cost. This is a monoplane of stick and wire construction with a wing area of about 6 square meters. Its total weight is about 30 kilograms.

It is provided with an automatic control for maintaining its direction and the tail plane can be set for any angle of glide that is desired. Instead of a landing gear it has a landing skid which is so bent over, under, and around the glider that when it comes in contact with the ground it can roll over and over without damage. The skid goes over the tail surface as well to protect it.

This target airplane can be dropped from an airplane or airship and provides an excellent opportunity for target practice from airplanes. These machines could be built cheaply and would afford an excellent means of keeping up aerial marksmanship.

GERMANY.

RÉSUMÉ OF GERMAN RESEARCH DEVELOPMENT IN AIRCRAFT CONSTRUCTION.

The treaty of Versailles gave the Allies the power to regulate the construction of aircraft in Germany. The allied powers issued an ultimatum on May 5, 1921, compelling the German Government to publish a law prohibiting all aircraft construction in Germany. This law is being carefully observed by all aircraft manufacturers and no new aircraft have been constructed since about July 1, 1921. However, on May 5, 1922, a certain leniency will be shown by the Allies toward German aircraft manufacturers to allow construction to take place on commercial types, limited in horsepower and in scope of possible interchangeability features that might render them convertible into military types.

Under the treaty of Versailles, Germany is prohibited from the manufacture and export of any war material; consequently there has been no new development in Germany since the end of the war.

The difficulty encountered in Germany in welding duralumin parts and fittings has not been overcome. The three leading German firms which have used duralumin in aircraft construction are the Junker Co., the Zeppelin Co., and the Shuttelanz Co. All the constructors agreed that riveting processes are not economical from a manufacturing standpoint, and continued research toward eliminating this method is being maintained.

The Lachmann air foil data, which is analogous to the famous Handley-Page type, is now being translated by the Berlin air attache's office and will be forwarded when completed.

The only adjustable pitch propellers designed in Germany have been designed and constructed by the Helix Maschinenbau Co., Berlin. These propellers are constructed under patents belonging to Doctor Reissner. The latest develpments in the adjustable pitch propeller are embodied in a sample propeller which was sent to the N. A. C. A., Washington, D. C., in October, 1921. Due to the prohibition against aircraft construction of all kinds in Germany, no adjustable pitch propellers of the latest type designed by the Helix Co. have been put into service. The last practicable service use in Germany of the Reissner adjustable pitch propeller was in 1918, when two of this type were used on the R-30, a Staaken giant airplane. They received about a six months' service test.

Four Haw propellers were used during the summer of 1921 on airplanes of the Ostflug Co., operating an air mail and passenger service between Berlin and Konigsberg, East Prussia. A few other Haw propellers, probably not more than 10, have been used in test flights by the five other air traffic companies operating in Germany during the past year.

The best German bomb sights developed during the war were designed and produced by the C. P. Goerz Optical Co., of Berlin. Numerous reports on their production and characteristics, however, have been received by our Air Service, and Mr. Spahn was in America during 1921, and is now in the States again for the specific purpose of discussing the taking over by our Government of the Goerz bomb sights and patents.

One of the best aircraft machine guns produced in Germany during the war was the Gast double-barreled type. This gun was turned over to the ordnance officer, American Forces in Germany, Coblenz, in December, 1921, for shipment to the Chief of Ordnance, Washington, D. C.

With respect to the subjects of magnesia alloys, cooling systems, power plants, fuel systems, superchargers, radio, airdrome illumination, oxygen apparatus, navigation instruments, photographic materials, methods of designing for controllability and stability, and data on methods which have been used by Doctor Parndtl, all have been obtained in publications or treatises in German, which are now being translated by our military attache's office in Berlin and will be forwarded as soon as possible.

ZEPPELIN AIRSHIPS.

The Zeppelin lighter-than-air main plant is located at Friedrichshafen. The main Zeppelin Co. is not at present engaged in the manufacture of any lighter-than-air equipment. This information was procured from Doctor Eckner and Mr. Dorr, the directors of the Zeppelin Co. Mr. Dorr has been chief designer and engineer of the Zeppelin Co. for 22 years. The company has a very small operating organization at present, principally made up of the heads of departments. One building has been entirely given over to museum purposes, where all the successive stages of Zeppelin experimentation, designs, and models of power-plant installation in Zeppelin units are assembled in operating fashion, so as to demonstrate to interested parties peculiar functions of clutches and pertinent units of power-plant installation. The directors are very much concerned over the possibility of receiving an order from the United States Navy for a large Navy type Zeppelin, but realize that negotiations for the construction of this ship will probably be drawn out for a long time.

Doctor Eckner claims that semirigids are more efficient in small sizes than in large sizes, but that the dirigibles are far superior for larger weight-carrying types. He gives the following comparisons:

PARSEVAL.	ZEPPELIN.
32,000 cubic meters: 20 metric tons.	32,000 cubic meters: 17 metric tons (useful load).
56,000 cubic meters: 35 metric tons (estimated).	56,000 cubic meters: 39½ metric tons.

Relative data on Zeppelin airship for the United States and last German naval type:

	L-2114, GERMAN NAVAL TYPE.	PROPOSED U. S. NAVY SHIP.
Greatest length	226.5 meters	206 meters.
Greatest diameter	23.9 meters	27.9 meters.
Greatest height	27.8 meters	31 meters.
Greatest breadth	23.9 meters	28 meters.
Gas content	68,500 cubic meters	68,000 cubic meters.
Power per engine	240 horsepower	400 horsepower.
Number of engines	6	5.
Total power	1,440 horsepower	2,000 horsepower.
Maximum velocity	32 meters per second	36 meters per second.
Weight, empty	32 metric tons	35 metric tons.
Useful load	47½ metric tons	46½ metric tons (which depends on U. S. requirements of strength desired). Cabin for 30 persons with sleeping quarters.

Below are given charts and explanatory data from Doctor Eckner relative to the comparison of airships and the use of nondimensional characteristics.

The characteristic data of all the different Zeppelin models, from their first model to the last war-time model, giving their construction number, where built, name or mark, whose property, capacity in cubic meters, and all data relative to Zeppelin accidents also follows.

Construction No.	Number of compartments.	Length.	Diameter.	Carrying power at 0.76 millimeter.	Number of motors.	Horsepower of each motor.	Total horsepower.
		Meters.	*Meters.*	*Kilograms.*			
LZ-1	17	128	11.65	....	2	14.7	29
LZ-2	16	128	11.65	[1] 2,700	2	85	170
LZ-3	16	128	11.65	[1] 2,700	2	85	170
	17	136	11.65	[1] 2,700	2	100	200
LZ-4	17	136	13	[1] 4,500	2	100	200
LZ-5	17	136	13	[1] 4,500	2	100	200
	17	136	13	[1] 4,500	2	115	230
LZ-6	18	144	13	[1] 4,000	3	{2 of 115 1 of 140}	370
LZ-7	18	148	14	[1] 6,500	3	120	360
LZ-8	18	148	14	[1] 6,500	3	120	360
LZ-9	16	132	14	....	3	140	420
	17	140	14	[1] 6,000	3	140	420
LZ-10	17	140	14	[1] 6,000	3	140	420
LZ-11	18	148	14	[1] 6,200	3	140	420
LZ-12	17	140	14	[1] 6,000	3	140	420
LZ-13	18	148	14	[1] 6,200	3	165	495
LZ-14	18	158	14.86	[1] 8,600	3	165	495
LZ-15	16	142	14.86	[1] 7,050	3	165	495
LZ-16	16	142	14.86	[1] 7,000	3	165	495
LZ-17	16	140	14.86	[1] 7,000	3	165	495
	17	148	14.86	[1] 7,500	3	165	495
LZ-18	18	158	16.6	[1] 11,000	4	165	660
LZ-19	16	140	14.86	[1] 7,000	3	165	495
LZ-20	16	140	14.86	[1] 7,000	3	165	495
	17	148	14.86	[1] 7,400	3	165	495
LZ-21	17	148	14.86	7,500	3	165	495
LZ-22	18	156	14.86	8,000	3	175	525
LZ-23	18	156	14.86	8,000	3	175	525
LZ-24	18	158	14.86	8,700	3	210	630
LZ-25	18	158	14.86	8,700	3	210	630
LZ-26	15	161.2	16	11,000	3	210	360
LZ-27	18	158	14.86	8,700	3	210	360
LZ-28	18	158	14.86	8,700	3	210	360
LZ-29	18	158	14.86	8,700	3	210	360
LZ-30	18	158	14.86	8,700	3	210	360
LZ-31	18	158	14.86	8,700	3	210	360
LZ-32	18	158	14.86	8,700	3	210	360
LZ-33	18	158	14.86	8,700	3	210	360
LZ-34	18	158	14.86	8,700	3	210	360
LZ-35	18	158	14.86	8,700	3	210	360
LZ-36	15	161.4	16	10,000	3	210	360
LZ-37	18	158	14.86	8,700	3	210	630
LZ-38	15	163.5	18.7	15,000	4	210	840
LZ-39	15	161.4	16	[2] 10,000	3	210	630
LZ-40	16	163.5	18.7	[2] 15,000	4	210	840
LZ-41	16	163.5	18.7	15,000	4	210	840
LZ-42	16	163.5	18.7	15,000	4	210	840
LZ-43	16	163.5	18.7	15,000	4	210	840
LZ-44	16	163.5	18.7	15,000	4	210	840
LZ-45	16	163.5	18.7	15,000	4	210	840
LZ-46	16	163.5	18.7	15,000	4	210	840
LZ-47	16	163.5	18.7	15,000	3 1	210 240	870
LZ-48	16	163.5	18.7	15,000	4	240	960
LZ-49	16	163.5	18.7	15,000	4	210	840
LZ-50	16	163.5	18.7	[1] 15,000	4	240	960
LZ-51	16	163.5	18.7	15,000	4	240	960
	18	178.5	18.7	17,500	4	240	960
LZ-52	16	163.5	18.7	15,000	4	240	960
LZ-53	16	163.5	18.7	15,000	4	240	960
LZ-54	16	163.5	18.7	15,000	4	240	960
LZ-55	16	163.5	18.7	15,000	4	210	840
LZ-56	16	163.5	18.7	15,000	4	210	840
	18	178.5	18.7	17,500	4	210	840

[1] About. [2] Recorded.

Construction No.	Number of compartments.	Length.	Diameter.	Carrying power at 0.76 millimeter.	Number of motors.	Horse-power of each motor.	Total horse-power.
		Meters.	*Meters.*	*Kilograms.*			
LZ-57	16	163.5	18.7	[1] 15,000	4	240	960
	18	178.5	18.7	17,500	4	240	960
LZ-58	16	163.5	18.7	15,000	4	210	840
	18	178.5	18.7	17,500	4	240	960
LZ-59	18	178.5	18.7	17,500	4	240	960
LZ-60	16	163.5	18.7	15,000	4	240	960
	18	178.5	18.7	17,500	4	240	960
LZ-61	18	178.5	18.7	17,500	4	240	960
LZ-62	19	198	23.9	28,700	6	240	1,440
LZ-63	16	163.5	18.7	15,000	4	210	840
	18	178.5	18.7	17,500	4	240	960
LZ-64	18	178.5	18.7	17,500	4	240	960
LZ-65	18	178.5	18.7	17,500	4	240	960
LZ-66	18	178.5	18.7	17,500	4	240	960
LZ-67	18	178.5	18.7	17,500	4	240	960
LZ-68	18	178.5	18.7	17,500	4	240	960
LZ-69	18	178.5	18.7	17,500	4	240	960
LZ-70 [3]	...	...	...	...	...	...	...
LZ-71	18	178.5	18.7	17,500	4	240	960
LZ-72	19	198	23.9	30,000	6	240	1,440
LZ-73	18	178.5	18.7	17,500	4	240	960
LZ-74	19	198	23.9	[1] 30,000	6	240	1,440
LZ-75	19	198	23.9	[1] 30,000	6	240	1,440
LZ-76	19	198	23.9	[1] 30,000	6	240	1,440
LZ-77	18	178.5	18.7	17,500	4	240	960
LZ-78	19	198	23.9	[1] 31,000	6	240	1,440
LZ-79	19	198	23.9	[1] 31,000	6	240	1,440
LZ-80	19	198	23.9	[1] 31,000	6	240	1,440
LZ-81	18	178.5	18.7	17,500	4	240	960
LZ-82	19	198	23.9	32,000	6	240	1,440
LZ-83	19	198	23.9	32,000-32,500	6	240	1,440
LZ-84	19	198	23.9	32,000-32,500	6	240	1,440
LZ-85	19	198	23.9	32,000-32,500	6	240	1,440
LZ-86	19	198	23.9	32,000-32,500	6	240	1,440
LZ-87	19	198	23.9	32,000-32,500	6	240	1,440
LZ-88	19	198	23.9	32,000-32,500	6	240	1,440
LZ-89	19	198	23.9	32,000-32,500	6	240	1,440
LZ-90	19	198	23.9	32,000-32,500	6	240	1,440
LZ-91	18	196.5	23.9	36,000	5	240	1,200
LZ-92	18	196.5	23.9	36,000	5	240	1,200
LZ-93	18	196.5	23.9	37,500	5	240	1,200
LZ-94	18	196.5	23.9	37,500	5	240	1,200
LZ-95	18	196.5	23.9	39,000	5	240	1,200
LZ-96	18	196.5	23.9	39,000	5	240	1,200
LZ-97	18	196.5	23.9	39,000	5	240	1,200
LZ-98	18	196.5	23.9	39,000	5	240	1,200
LZ-99	18	196.5	23.9	39,000	5	240	1,200
LZ-100	14	196.5	23.9	40,000	5	240	1,200
LZ-101	14	196.5	23.9	40,000	5	240	1,200
LZ-102	16	226.5	23.9	52,000	5	240	1,200
LZ-103	14	196.5	23.9	40,000	5	240	1,200
LZ-104	16	226.5	23.9	52,000	5	240	1,200
LZ-105	14	196.5	23.9	40,000	5	290	1,450
LZ-106	14	196.5	23.9	40,000	5	290	1,450
LZ-107	14	196.5	23.9	40,000	5	290	1,450
LZ-108	14	196.5	23.9	40,000	5	290	1,450
LZ-109	14	196.5	23.9	40,000	5	290	1,450
LZ-110	14	196.5	23.9	40,000	5	290	1,450
LZ-111	14	196.5	23.9	40,000	5	290	1,450
LZ-112	15	211.3	23.9	[1] 40,000	7	290	2,030
LZ-113	15	211.5	23.9	[1] 40,000	7	290	2,030
LZ-114	15	211.5	23.9	[1] 40,000	7	290	2,030
LZ-115-LZ-119, inclusive [4]	...	...	...	...	...	...	...
LZ-120	12	130	18.7	11,500	4	240	960
LZ-121	...	130	18.7	11,500	4	240	960

[1] About. [3] Construction suspended to clear yard for the LZ-71. [4] Not built.

Construction No.	Where built.	Name or mark.	Property of—	Capacity in cubic meters.
LZ-1	Manzell		Zepplin Co.	11,300
LZ-2	do		do	11,300
LZ-3	do		do	11,300
		Z I [1]	Military board	12,200
		Z I [2]	do	12,200
LZ-4	do		Zepplin Co.	15,000
LZ-5	do	Z II	Military board	15,000
LZ-6	Friedrichshafen		Zepplin Co.	15,000
			Delag [1]	16,000
LZ-7	do	Deutschland-Ersatz	do	19,300
LZ-8	do	Deutschland	do	19,300
LZ-9	do	Z II	Military board	16,800
		do. [1]	do	17,800
LZ-10	do	Schwaben	Delag	17,800
LZ-11	do	Victoria Louise	do	18,700
LZ-12	do	Z III	Military board	17,800
LZ-13	do	Hansa	Delag	18,700
LZ-14	do	L I	Naval board	22,465

[1] After reconstruction. [2] After reconstruction of steering gear

Construction No.	Where built.	Name or mark.	Property of—	Capacity in cubic meters.
LZ-15	Friedrickshafen	Ersatz Z I	Military board	19,500
LZ-16	do	Z IV	do	19,500
LZ-17	do	Sachsen	Delag	19,500
		Sachsen [3]	do	20,870
LZ-18	do	L 2	Naval board	27,000
LZ-19	do	Desatz Z I	Military board	19,500
LZ-20	do	Z V	do	19,500
	do	Z V	do	20,870
LZ-21	do	Z VI	do	20,870
LZ-22	do	Z VII	do	22,140
LZ-23	do	Z VIII	do	22,140
LZ-24	do	L 3	Naval board	22,500
LZ-25	do	X IX	Military board	22,500
LZ-26	Frankfort on the Main	Z XII	do	25,000
LZ-27	Friedrichshafen	L 4	Naval board	22,500
LZ-28	do	L 5	do	22,500
LZ-29	do	Z X	Military board	22,500
LZ-30	Potsdam	Z XI	do	22,500
LZ-31	Friedrichshafen	L 6	Naval board	22,500
LZ-32	do	L 7	do	22,500
LZ-33	do	L 8	do	22,500
LZ-34	Potsdam	LZ 34	Military board	22,500
LZ-35	Friedrichshafen	LZ 35	do	22,500
LZ-36	do	L 9	Naval board	25,000
LZ-37	Potsdam	LZ 37	Military board	22,500
LZ-38	Friedrichshafen	LZ 38	do	32,000
LZ-39	do	LZ 39	do	25,000
LZ-40	do	L 10	Naval board	32,000
LZ-41	Loewenthal	L 11	do	32,000
LZ-42	Potsdam	LZ 72	Military board	32,000
LZ-43	Friedrichshafen	L 12	Naval board	32,000
LZ-44	Loewenthal	LZ 74	Military board	32,000
LZ-45	Friedrichshafen	L 13	Naval board	32,000
LZ-46	Loewenthal	L 14	do	32,000
LZ-47	Friedrichshafen	LZ 77	Military board	32,000
LZ-48	Loewenthal	L 15	Naval board	32,000
LZ-49	Potsdam	LZ 79	Military board	32,000
LZ-50	Friedrichshafen	L 16	Naval board	32,000
LZ-51	Loewenthal	LZ 81	Military board	32,000
		LZ 81 [3]	do	35,800
LZ-52	do	LZ 18	Naval board	32,000
LZ-53	Friedrichshafen	L 17	do	32,000
LZ-54	do	L 19	do	32,000
LZ-55	Potsdam	LZ 85	Military board	32,000
LZ-56	do	LZ 86	do	32,000
			do [3]	35,800
LZ-57	Loewenthal	LZ 87	do	32,000
		LZ 87 [3]	do	35,800
LZ-58	Potsdam	LZ 88	do	32,000
		LZ 88 [3]	do	35,800
LZ-59	Friedrichshafen	L 20	Naval board	35,800
LZ-60	Potsdam	LZ 90	Military board	32,000
		LZ 90 [3]	do	35,800
LZ-61	Loewenthal	L 21	Naval board	35,800
LZ-62	Friedrichshafen	L 30	do	55,000
LZ-63	Potsdam	LZ 93	Military board	32,000
		LZ 93	do	35,800
LZ-64	Loewenthal	L 22	Naval board	35,800
LZ-65	Friedrichshafen	LZ 95	Military board	35,800
LZ-66	Potsdam	L 23	Naval board	35,800
LZ-67	Loewenthal	LZ 97	Military board	35,800
LZ-68	do	LZ 98	do	35,800
LZ-69	Potsdam	L 24	Naval board	35,800
LZ-70	Loewenthal	L 26	do	
LZ-71	Potsdam	LZ 101	Military board	35,800
LZ-72	Loewenthal	L 31	Naval board	55,000
LZ-73	Potsdam	LZ 103	Military board	35,800
LZ-74	Friedrichshafen	L 32	Naval board	55,000
LZ-75	Staaken	L 37	do	55,000
LZ-76	Friedrichshafen	L 33	do	55,000
LZ-77	Potsdam	LZ 107	Military board	35,800
LZ-78	Loewenthal	L 34	Naval board	55,000
LZ-79	Staaken	L 41	do	55,000
LZ-80	Friedrichshafen	L 35	do	55,000
LZ-81	Potsdam	LZ 111	Military board	35,800
LZ-82	Friedrichshafen	L 36	Naval board	55,000
LZ-83	Staaken	LZ 113	Military board	55,000
LZ-84	Loewenthal	L 38	Naval board	55,000
LZ-85	Staaken	L 45	do	55,000
LZ-86	Friedrichshafen	L 39	do	55,000
LZ-87	Staaken	L 47	do	55,000
LZ-88	Friedrichshafen	L 40	do	55,000
LZ-89	Staaken	L 50	do	55,000
LZ-90	Loewenthal	LZ 120	Military board	55,000
LZ-91	Friedrichshafen	L 42	Naval board	55,500
LZ-92	do	L 43	do	55,500
LZ-93	Loewenthal	L 44	do	55,800
LZ-94	Friedrichshafen	L 46	do	55,800
LZ-95	do	L 48	do	55,800
LZ-96	Loewenthal	L 49	do	55,800
LZ-97	Friedrichshafen	L 51	do	55,800
LZ-98	Staaken	L 52	do	55,800
LZ-99	do	L 54	do	55,800
LZ-100	Friedrichshafen	L 53	do	56,000
LZ-101	Loewenthal	L 55	do	56,000
LZ-102	Friedrichshafen	L 57	do	68,500
LZ-103	Staaken	L 56	do	56,000

[3] After elongation.

Construction No.	Where built.	Name or mark.	Property of—	Capacity in cubic meters.
LZ-104	Staaken	L 59	Naval board	68,500
LZ-105	Friedrichshafen	L 58	do.	56,000
LZ-106	do.	L 61	do.	56,000
LZ-107	Loewenthal	L 62	do.	56,000
LZ-108	Staaken	L 60	do.	56,000
LZ-109	do.	L 64	do.	56,000
LZ-110	Friedrichshafen	L 63	do.	56,000
LZ-111	Loewenthal	L 65	do.	56,000
LZ-112	Friedrichshafen	L 70	do.	68,150
LZ-113	do.	L 71	do.	62,200
LZ-114	Loewenthal	L 72	do.	68,150
LZ-115[4]				
LZ-116[4]				
LZ-117[4]				
LZ-118[4]				
LZ-119[4]				
LZ-120	Friedrichshafen	Bodensee Bodensee[3]	Delag do.	22,560
LZ-121		Nordstern	do.	22,560

[3] After elongation.

[4] Not built.

Construction No.	Velocity (meters per second).	First trip.	Put out of commission.	Remarks.
LZ-1	8	July 2, 1900	Spring, 1901	Dismantled at the factory.
LZ-2	11	Nov. 30, 1905	Jan. 17, 1906	Destroyed by storm after a forced landing at Kiessling, Allaueg.
LZ-3	11 12.2 15	Oct. 9, 1906		Antiquated; dismantled at the Metz shed.
LZ-4	12.5	June 20, 1908	Aug. 5, 1908	Forced landing at Echterdingen; destroyed by fire later.
LZ-5	12.5	May 26, 1909	Apr. 25, 1910	Forced landing at Weilburg; torn loose by storm and wrecked.
LZ-6	13 15.5	Aug. 25, 1909	Sept. 14, 1910 do.	Destroyed by fire at shed at Baden-Oos.
LZ-7	16	June 19, 1910	June 28, 1910	Wrecked at Wallendorf (Teuburg Forest).
LZ-8	16	Mar. 30, 1911	May 16, 1911	Destroyed on starting from shed at Dusseldorf.
LZ-9	21.7 21	Oct. 2, 1911	Aug. 1, 1914	Antiquated; dismantled in the shed at Gotha.
LZ-10	21	June 26, 1911	June 28, 1912	Destroyed by fire at Dusseldorf.
LZ-11	[1] 21	Feb. 14, 1912	Autumn, 1915	Destroyed when entering the shed at Liegnitz.
LZ-12	[1] 21	Apr. 25, 1912	Summer, 1914	Antiquated; dismantled in shed at Metz.
LZ-13	[1] 21	July 30, 1912	Summer, 1916	Antiquated; dismantled at shed in Johannisthal.
LZ-14	21.2	Oct. 7, 1912	Sept. 9, 1913	Wrecked at Helgoland.
LZ-15	20.5	Jan. 16, 1913	Mar. 19, 1913	Forced landing at Karlsruhe and destroyed by storm.
LZ-16	20.9	Mar. 14, 1913	Autumn, 1916	Antiquated; dismantled in shed at Hutembog.
LZ-17	[1] 21 20	May 3, 1913	Autumn, 1916	Antiquated; dismantled in shed at Duren.
LZ-18	21	Sept. 9, 1913	Oct. 17, 1913	Descended in a burning state at Johannisthal.
LZ-19	20.4	June 6, 1913	June 13, 1914	Forced landing at Dedenhofen and wrecked.
LZ-20	20.5	July 8, 1913	Aug. 27, 1914	Shot down at Kipoviec (Mlawa) and wrecked.
LZ-21	20.3	Nov. 10, 1913	Aug. 6, 1914	Shot down at Luttich and wrecked at Cologne.
LZ-22	20.5	Jan. 8, 1914	Aug. 23, 1914	Shot down while reconnoitering and wrecked at St. Quirin.
LZ-23	20.2	Feb. 21, 1914	do.	Hit by shell while reconnoitering and wrecked at Badenvillers.
LZ-24	21.5	May 11, 1914	Feb. 17, 1915	Wrecked by storm on the shore of Tano in consequence of the breakdown of all motors.
LZ-25	21.4	July 29, 1914	Oct. 8, 1914	Destroyed by English aviators in the shed at Dusseldorf.
LZ-26	21.4	do.	do.	Dismantled in the Juterbog shed on cessation of military airship aviation.
LZ-27	[1] 21.5	Aug. 28, 1913	Feb. 17, 1915	Driven by storm to Denmark and wrecked at Borsmose.
LZ-28	[1] 21.5	Sept. 22, 1913	Aug. 6, 1915	Shot down and wrecked at Mitau.
LZ-29	[1] 22	Oct. 13, 1914	Mar. 21, 1915	Hit by shell during an attack on Paris and wrecked at St. Quentin.
LZ-30	22	Nov. 11, 1914	May 20, 1915	Cast adrift by storm when leaving the shed at Posen; wrecked and destroyed by fire.
LZ-31	22	Nov. 3, 1914	Sept. 19, 1916	Destroyed by fire in the shed at Fuhlsbuttel.
LZ-32	22	Nov. 20, 1914	May 5, 1916	Brought down by shell while reconnoitering at Horns Riff.
LZ-33	22	Dec. 17, 1914	Mar. 5, 1915	Shot down and wrecked at Tirlemont.
LZ-34	22	Jan. 6, 1915	May 21, 1915	Shot down during an attack on Kowno, forced landing in East Prussia, cast adrift and destroyed by fire.
LZ-35	22	Jan. 11, 1915	May 13, 1915	Shot down during an attack on Poperinghe and wrecked at Thielt.
LZ-36	22	Mar. 8, 1915	Sept. 16, 1916	Destroyed by fire in the shed at Fuhlsbuttel.
LZ-37	22	Feb. 28, 1915	June 7, 1915	Hit by aviators at Ghent after an attack on Calais.

[1] About.

Construction No.	Velocity (meters per second).	First trip.	Put out of commission.	Remarks.
LZ-38	23	May 3, 1915	June 7, 1915	Destroyed in the shed at Brussels by English aviators.
LZ-39	21.5	Apr. 24, 1915	Oct. 18, 1915	Shot down during an attack on Rowno and wrecked at Luck.
LZ-40	[1] 25	May 13, 1915	Sept. 3. 1915	Struck by lightning, at Cuxhaven and descended in a burning state.
LZ-41	[1] 25	June 7, 1915	Apr.—, 1917	Antiquated; dismantled in the shed at Hage.
LZ-42	[1] 25	June 15, 1915	Feb. 16, 1917	Dismantled in the shed at Juterbog in consequence of the cessation of military aviation.
LZ-43	[1] 25	June 21, 1915	Aug. 10, 1915	Shot down during an attack on England, dragged into the port of Ostend and there burned.
LZ-44	[1] 25	July 8, 1915	Oct. 8, 1915	Collision at Berg in Belgium and wrecked.
LZ-45	[1] 25	July 23, 1915	Apr.—, 1917	Antiquated; dismantled in shed at Hage.
LZ-46	[1] 25	Aug. 9, 1915	July—, 1919	Destroyed in shed at Nordholz.
LZ-47	[1] 25	Aug. 24, 1915	Feb. 21, 1916	Shot down at Revigny.
LZ-48	[1] 25	Sept. 9, 1915	Apr. 1, 1916	Forced landing at the mouth of the Thames after an attack on England and sunk.
LZ-49	[1] 25	Aug. 2, 1915	Jan. 20, 1916	Shot down during an attack on Paris, forced landing at Ath and wrecked.
LZ-50	[1] 25	Sept. 23, 1915	Oct. 19, 1917	Destroyed in consequence of difficult landing at Nordholz.
LZ-51	[1] 25	Oct. 7, 1915	Sept. 27, 1916	Shot down during attack on Bucarest, forced landing at Trnovo and wrecked.
LZ-52	[1] 25	Nov. 3, 1915	Nov. 17, 1915	Destroyed by fire in shed at Tondern.
LZ-53	[1] 25	Oct. 20, 1915	Dec. 28, 1916	Do.
LZ-54	[1] 25	Nov. 27, 1915	Feb. 2, 1916	Sunk in the North Sea.
LZ-55	[1] 25	Sept. 12, 1915	May 5, 1916	Shot down during attack on Saloniki, forced landing at the Wardar and wrecked.
LZ-56	[1] 25	Oct. 10, 1915	Sept. 4, 1916	Destroyed in consequence of difficult landing at Temesvar.
LZ-57	[1] 25	Dec. 6, 1915	July 28, 1917	Dismantled in the shed at Juterbog in consequence of cessation of military airship aviation.
LZ-58	[1] 25	Nov. 15, 1915	Sept. 15, 1917	Taken over by the naval board as trial ship L-25, antiquated and dismantled in shed at Potsdam.
LZ-59	[1] 25	Dec. 21, 1915	May 3, 1916	Driven to Stavanger in consequence of defective motors after an attack on England and wrecked.
LZ-60	[1] 25	Jan. 1, 1916	Nov. 7, 1916	Torn loose without a crew by storm at Wittmund and and lost at sea.
LZ-61	25	Jan. 10, 1916	Nov. 28, 1916	Brought down on the English coast at Lowestoft.
LZ-62	27.8	May 28, 1916	Summer, 1920	Dismantled in shed at Seerappen.
LZ-63	25	Feb. 23, 1916	Summer, 1917	Dismantled in the shed at Trier in consequence of cessation of militare airship aviation.
LZ-64	25	Mar. 3, 1916	May 14, 1917	Brought down by torpedo boats at Terschelling.
LZ-65	[2] 25	Jan. 31, 1916	Feb. 22, 1916	Hit by shell while crossing the front in the Champagne and wrecked at Namur.
LZ-66	([2])	Apr. 8, 1916	Aug. 22, 1917	Brought down by torpedo boats at Horns Riff.
LZ-67	([2])	Apr. 4, 1916	July 5, 1917	Dismantled in the shed at Juterbog in consequence of cessation of military airship aviation.
LZ-68	([2])	Apr. 28, 1916	Aug.—, 1917	Dismantled for same reason at shed at Schneidemuehl.
LZ-69	([2])	May 20, 1916	Dec. 28, 1916	Destroyed by fire in the shed at Tondern.
LZ-70 [3]				
LZ-71	25	June 29, 1916	Sept.—, 1917	Dismantled in consequence of cessation of military airship aviation in shed at Juterbog.
LZ-72	27	July 12, 1916	Oct. 2, 1916	Brought down by shell during an attack on London.
LZ-73	25	Aug. 8, 1918	Aug.—, 1917	Dismantled in the shed of Konigsberg in consequence of cessation of military airship aviation.
LZ-74	[1] 27	Aug. 4, 1916	Sept. 24, 1916	Brought down by shell during an attack on London.
LZ-75	[1] 27	Nov. 9, 1916	Summer, 1920	Taken apart in the shed of Seddin, to be reconstructed in Japan.
LZ-76	[1] 27	Aug. 30, 1916	Sept. 24, 1916	Hit by shell, forced landing at Brentwood (Engand) and dismantled there.
LZ-77	25	Oct. 16, 1916	July—, 1917	Dismantled at shed at Darstadt in consequence of cessation of military airship aviation.
LZ-78	[1] 27	Sept. 22, 1916	Nov. 28, 1916	Brought down by English aviators at Scarborough (English coast).
LZ-79	[1] 27	Jan. 15, 1917	July —, 1917	Destroyed in the shed at Nordholz.
LZ-80	[1] 27	Oct. 12, 1916	Summer, 1918	Antiquated; dismantled in the shed at Juterbog.
LZ-81	25	Dec. 20, 1916	Aug. 10, 1917	Dismantled in the shed at Dresden in consequence of cessation of military airship aviation.
LZ-82	27	Nov. 1, 1916	Feb. 7, 1917	Wrecked in the fog at Rethem (Aller).
LZ-83	[1] 28	Feb. 22, 1917	Oct. 8, 1920	Transported from Seddin to Maubeuge and delivered to the French.
LZ-84	[1] 28	Nov. 22, 1916	Dec. 29, 1916	Wrecked at Seemuppen, (Russia).
LZ-85	[1] 28	May 2, 1917	Oct. 20, 1917	Wrecked in the Valley of the Saone after an attack on England.
LZ-86	[1] 28	Dec. 11, 1916	Mar. 17, 1917	Brought down by shell at Compiegne.
LZ-87	[1] 28	May 1, 1917	Jan. 5, 1918	Destroyed by fire in consequence of an explosion in the shed at Ahlhorn.

[1] About. [2] Recorded. [3] Discontinued. Construction of airships of 55,000 m^3 commenced.

Construction No.	Velocity (meters per second).	First trip.	Put out of commission.	Remarks.
LZ-88	[1] 28	Jan. 3, 1917	June 17, 1917	Wrecked at Neuenwalde (Geestemunde).
LZ-89	[1] 28	June 9, 1917	Oct. 20, 1917	Incidental landing at Montigny le Roi (France) after an attack on England and wrecked in Switzerland.
LZ-90	[1] 28	Jan. 31, 1917	....	Shortly to be transported from Seerappen near Konigsberg to Rome and delivered to Italy.
LZ-91	[1] 27	Feb. 21, 1917	July —, 1919	Destroyed in the shed at Nordholz.
LZ-92	[1] 27	Mar. 6, 1917	June 14, 1917	Brought down by English military forces over the North Sea.
LZ-93	[1] 27	Apr. 1, 1917	Oct. 20, 1917	Driven by storm after an attack on England and brought down by shells in France.
LZ-94	[1] 27	Apr. 24, 1917	Jan. 5, 1918	Destroyed by explosion in the shed at Ahlhorn.
LZ-95	[1] 29.5	May 22, 1917	June 17, 1917	Brought down by shell at Ipswich.
LZ-96	[1] 29.5	June 13, 1917	Oct. 20, 1917	Driven by storm after an attack on England at Bouchen les Bains and wrecked in France.
LZ-97	[1] 29.5	July 6, 1917	Jan. 5, 1918	Destroyed by fire in the shed at Ahlhorn.
LZ-98	[1] 29.5	July 4, 1917	Aug. —, 1919	Destroyed in the shed at Wittmund.
LZ-99	[1] 29.5	Aug. 13, 1917	July 19, 1918	Destroyed by English aviators in the shed at Tondern.
LX-100	30	Aug. 18, 1917	Aug. 11, 1918	Shelled at Terschelling.
LZ-101	30	Sept. 1, 1917	Oct. 20, 1917	Hit by shell during an attack on England and wrecked at Tiefenort (Werra).
LZ-102	28	Sept. 26, 1917	Oct. 7, 1917	Destroyed by fire in front of the shed at Juterbog.
LZ-103	30	Sept. 24, 1917	Aug. —, 1919	Destroyed in the shed at Wittmund.
LZ-104	28	Oct. 10, 1917	Apr. 7, 1918	Descended in a burning state in the streets of Otranto (cause unknown).
LZ-105	[1] 32	Oct. 29, 1917	Jan. 5, 1918	Destroyed by explosion in shed at Ahlhorn.
LZ-106	[1] 32	Dec. 12, 1917	Aug. 29, 1918	Transported from Wittmund to Rome and delivered to Italy.
LZ-107	[1] 32	Jan. 19, 1918	May 10, 1918	Descended in Helgoland.
LZ-108	[1] 32	Dec. 18, 1917	July 19, 1918	Destroyed by English aviators in the shed at Tondern.
LZ-109	[1] 32	Mar. 11, 1918	July 22, 1920	Transported from Ahlhorn to Pulham and delivered to England.
LZ-110	[1] 32	Mar. 4, 1918	July —, 1919	Destroyed in the shed at Nordholz.
LZ-111	[1] 32	Apr. 17, 1918	.....do........	Do.
LZ-112	[1] 36	July 1, 1918	Aug. 5, 1918	Brought down by shell at Boston.
LZ-113	[1] 36	July 29, 1918	July 1, 1920	Transported from Ahlhorn to Pulham and delivered to England.
LZ-114	[1] 36	July 9, 1920	....	Transported from Loewenthal to Maubeuge and delivered to France.
LZ-115[4]	......	....	....	
LZ-116[4]	......	....	....	
LZ-117[4]	......	....	....	
LZ-118[4]	......	....	....	
LZ-119[4]	......	....	....	
LZ-120	[1] 37	Aug. 20, 1919	....	After elongation not commissioned, owing to prohibition by Entente.
LZ-121	......	....	....	Not commissioned, owing to prohibition by Entente.

[1] About

[4] Not built.

ACCIDENTS TO ZEPPELINS.

1. *Airship No. II* (no designation). Was forced down by a storm at Kiessling; ship could not be controlled, due to heavy wind. Made forced landing. Blown against trees (or buildings); frame broke, could not be repaired. Cause: Lack of power to make headway against storm. January 17, 1906.

2. *Airship No. IV* (no designation). Was compelled to land, due to lack of buoyancy, at Echterdingen. In attempting to make repairs one of the gas cells caught fire and the ship was burned. Cause: Lack of proper precautions in deflating. August, 1908.

3. *Z-II.* Was compelled to land, on account of motor trouble, at Woilking. Not sufficiently held down; while awaiting minor repairs a storm broke, tore airship from moorings, and carried it off; destroyed when crashed into the ground. April, 1910.

4. *Airship No. 6* (no designation). Burned up when a fire broke out in the hangar at Badenoos. September 14, 1910.

5. *Deutschland* (*I*). Was compelled to land on account of lack of lift (leaky gas bags) on the trees, in Teutoberger Forest. Airship could not be salvaged and it became necessary to break it up June 28, 1910.

6. *Deutschland* (*II*). Was caught in a wind gust on emerging from hangar (due to presence of windbreaks). Airship was thrown against side of hangar door and broken. Could not be repaired. May 16, 1911.

7. *Schwaben.* Was burned up at Dusseldorf, due to fire in hangar, June 28, 1912. (No details are now available.)

8. *Victoria Louise.* Was broken on entering hangar at Leegnitz, due to very strong wind, insufficient hangar space, and untrained handling detachment. Airship was carried against side of hangar, caught in framework of latter, and the frame of the airship was broken. Autumn, 1915.

9. *L-I.* Was carried out to sea by strong wind, due to lack of buoyancy, and stranded at Helgoland, September, 1913. (No further details now available.)

10. *Z-I* (substitute). Was compelled to make an emergency landing on account of a severe storm. Could not be properly moored down. The force of the storm drove the airship against the ground on its moorings and broke the frame. March 19, 1913.

11. *L-II.* Caught fire in the air, due to spark from the motor exhaust (due to motor being too close to envelope). Burned up. Johannisthal, October 17, 1913.

12. *Z-I* (second substitute). Emergency landing due to lack of gas (bad piloting and leaky gas cells). Could

not be moored down, account local conditions (no means of attachment). Ship broken on landing and later severely damaged by force of wind while on ground. June 13, 1914.

13. *Z-V.* No report.

14. *Z-VI.* No report.

15. *Z-VII.* No report.

16. *Z-VIII.* No report.

17. *L-III.* All three motors stopped, and to prevent being carried out to sea was landed on a small island in Baltic. Severe storm at the time severely damaged airship on landing, and it was later more damaged, so that it could not be repaired. February 17, 1915.

18. *Z-IX.* Destroyed in hangar by British aviators. Bombed hangar, and set fire to airship. Dusseldorf, October 8, 1914.

19. *L-IV.* Was driven to Denmark by severe storm (due to lack of dirigibility), landed, and destroyed. February 17, 1915.

20. *L-V.* Struck by hostile projectiles and fell (no information available). March 21, 1915.

21. *Z-X.* No report.

22. *Z-XI.* Was carried off on taking out of hangar (due to wind, lack of sufficient handling crew, and local conditions); landed in enemy territory and burned up by crew. May 20, 1915.

23. *L-VI.* Burned up as a result of fire in the hangar at Fruhlsbuttel. (No details available.) September, 1916.

24. *L-VIII.* Struck by enemy projectiles, forced to land on account of loss of gas and damaged controls. Could not be repaired. Tirlemenet, March 5, 1915.

25. *L-VII.* Was struck and severely damaged by hostile artillery fire; compelled to land in water and sunk. May 4, 1915.

26. *LZ-34.* Was damaged in bombing Kovno; lost gas and was compelled to make forced landing in East Prussia. Ship was blown against a building and fire from signal rockets ignited gas. May 21, 1915.

27. *LZ-35.* Was struck on making bombing attack on Poperinghe; lost gas and was landed at Thielt. Struck with great force, breaking frame, and could not be repaired. April 13, 1915.

28. *L-IX.* Burned in hangar at Fuhlsbuttel at same time as *L-6*.

29. *LZ-37.* Was attacked by airplanes and, due to loss of gas, fell near Ghent. Destroyed on landing. June 7, 1915.

30. *LZ-38.* Destroyed when hangar at Brussels was bombed. June, 1915.

31. *LZ-39.* Was struck in bombing Rovno and forced to land. Burned by crew to avoid capture. December 18, 1915.

32. *L-10.* Was struck by lightning and immediately caught fire over Cuxhaven. Burned up in the air. September 3, 1915.

33. *L-12.* Was struck by hostile artillery in bombing England. Landed on Belgian coast and carried overland to Ostend; damaged in last operation too severely to be repaired, and therefore burned. August 10, 1915.

34. *LZ-77.* Shot down at Revigny and burned by crew to avoid capture. February 21, 1916.

35. *L-15.* Was so severely damaged in bombing attack on England (due to planes and antiaircraft fire) that it was compelled to land at mouth of Thames. Sunk by crew to avoid capture. April 1, 1916.

36. *LZ-79.* Was damaged by antiaircraft and airplane fire on bombing Paris. Loss of gas compelled landing at Ath. No facilities for repairs, and ship was destroyed to avoid possibility of later capture by French. January 30, 1916.

37. *L-16.* Was damaged on entering Nordholz hangar, due to sudden wind gust driving it against the framework of latter. Was not deemed advisable to make repairs on account of it being an older type, and it was therefore destroyed. Cause of damage principally attributed to strong wind gust and presence of other airships in hangar. October 19, 1917.

38. *LZ-81.* Was struck several times by large-caliber projectiles over Bucharest; forced, account of loss of gas, to make an emergency landing and abandoned as being beyond repair, due to both causes. September 27, 1916.

39. *L-17* and *L-18.* Burned up when a fire broke out in the hangar at Tondern. There were two separate fires (November 17, 1915, and December 28, 1915), due to same cause (ignition of inflammable material).

40. *L-19.* Sunk in the North Sea. Cause not definitely known, probably as a result of hostile aircraft or gun fire. November 27, 1915.

41. *LZ-85.* Struck numerous times by hostile fire at Saloniki, lost gas and forced to land. Unable to be repaired and therefore broken up. May 5, 1916.

42. *LZ-86.* Attempted to land in a high wind and with a new crew. Crashed into a tree (or trees), broke nose and cars. Was too severely damaged to be repaired. September 4, 1916.

43. *L-20.* On a bombing raid over England, was driven off by British airplanes. On return trip developed serious motor trouble and was no longer dirigible. Made a forced landing at Stavenger. Could not be repaired. May 3, 1916.

44. *LZ-90.* Was torn from its moorings at Wittmund in a sudden storm before it could be housed. Was carried away to sea and disappeared with no personnel aboard. November 7, 1916.

45. *L-21.* Was shot down, probably by British aircraft, near the English coast. No details known. November 28, 1916.

46. *L-22.* Attempted to bomb a British submarine near Terschilling. Was caught by British torpedo boats and shot down by gunfire from the latter. May 14, 1917.

47. *LZ-95.* Was struck by hostile gunfire on crossing over the lines in Champagne. Turned and made a forced landing at Namur, but was too badly damaged to be repaired. February 26, 1916.

48. *L-23.* An accident similar in every respect to that of *L-22*.

49. *LZ-98.* Burned up with *L-17* in the hangar at Tondern.

50. *LZ-101.* Shot down in a bombing raid over London; no details known. October 2, 1916.

51. *L-32.* Shot down in an attack on London. Struck by antiaircraft fire and compelled to descend to a lower level where it was attacked by planes and finally compelled

to land in the North Sea. Was sunk. September 24, 1916.

52. *L-33*. Shot down by British airplanes at Brentwood England. Lost gas; made a forced landing and was broken up by crew to avoid capture. September 24, 1916.

53. *L-34*. Shot down by British aviators over Scarborough, England. Compelled to land, account of loss of gas, and sunk in North Sea. November 28, 1916.

54. *L-36*. Lost its way in a fog and made a forced landing at Rethem. Severely damaged on landing and was broken up. February 7, 1917.

55. *L-38*. Compelled to land in Russia and was either broken up by crew or captured (details unknown). December 29, 1916.

56. *L-45*. After an attack in England, lost its bearings and flew over France. Fog prevented orientation and finally was compelled to land, account of no fuel and lack of gas. Captured by French, October 20, 1917.

57. *L-39*. Shot down in attempting to cross lines near Compiegne. Ship was compelled to land almost immediately and was captured. March 17, 1917.

58. *L-47*. Destroyed in Ahlhorn when fire broke out and gas bags were ignited. Ship exploded when it caught fire. January 5, 1918.

59. *L-40*. Compelled to land near Neuenwalde, and broken up (no details known). June, 1917.

60. *L-50*. Followed *L-45* over France. Made a forced landing at Montigny, discovered its location and then flew to Switzerland. Broken up there and crew interned. October 20, 1917.

61. *L-43*. Shot down and destroyed by British planes in North Sea. (No details known.) June, 1917.

62. *L-44*. Followed *L-45* over France, and was forced to land in France on account of lack of gas and motor trouble. Badly damaged by gunfire from French antiaircraft cannon.

63. *L-46*. Destroyed with *L-47* at Ahlhorn hangar.

64. *L-48*. Compelled to land at Ipswich, England, on account of loss of gas and motor trouble, due to British antiaircraft. June 17, 1917.

65. *L-49*. Followed *L-45* over France, ran out of fuel and was leaking gas badly. Forced to land at Bouchon les Bains and captured before it could be broken up or destroyed.

66. *L-51*. Destroyed in Ahlhorn hangar with *L-46* and *L-47*.

67. *L-54*. Was destroyed in hangar at Tondern when the hangar was bombed by British planes. Bomb struck the airship and it exploded. July 19, 1918.

68. *L-53*. Was compelled to land at Terschelling on account of lack of gas, due to shot holes in bags. Broken up and destroyed. August 11, 1918.

69. *L-55*. Was severely damaged by antiaircraft gunfire when attacking England with *L-44*, *L-45*, *L-49*, and *L-50*. Attempted to regain its hangar at Ahlhorn but was forced to land at Tienfenert, and broken up.

70. *L-57*. Was designed to take the trip to German East Africa, but on coming back from a flight, was burned up on catching fire when about to be taken into the hangar. Fire due to burning gasoline from the motor. October 7, 1917.

71. *L-59*. No details of this accident are known, except that the airship was observed crossing the Straits of Otranto, and suddenly caught fire. It dropped into the water burning, and there were no survivors. April 7, 1918.

72. *L-58*. Was destroyed in the hangar at Ahlhorn with *L-46*, *L-47*, and *L-51*.

NOTE.—The explosion in one of the Ahlhorn hangars caused a general outbreak of fire which spread to the adjoining hangars.

73. *L-62*. Was cruising in North Sea, and compelled to make forced landing on Helgoland. Driven violently against rocks by storm and broken to pieces. May 10, 1918.

74. *L-60*. Was destroyed in the hangar at Tondern by British planes, at the same time as *L-54*.

75. *L-70*. Was shot down by British planes and antiaircraft gunfire at Boston. Ship was destroyed to avoid capture. August 5, 1918.

NOTE.—The above represents the principal accidents to Zeppelins. There were, of course, several other accidents of a minor nature, but it was not possible to obtain the details.

The *Bodensee* is now in possession of the Italian Air Service and located at Cianino, the Italian lighter-than-air station located just outside of Rome. This machine is in full flight operation. The *Nordstorn* has been taken over by the French Air Service and is located just outside of Paris and is in flying condition. The *L-72* has also been taken over by the French Air Service and is located at Cuers. It was described under France.

THE COMPARISONS OF AIRSHIPS AND THE USE OF NONDIMENSIONAL CHARACTERISTICS.

When describing airships, their characteristics are usually expressed in terms of the ship's size and engine power as well as of lift and speed. These figures tell what performance each particular ship is able to give and what structural weight and power have been required in order to make this performance possible. In this case performance means the greatest absolute speed in a horizontal direction and the greatest useful load that the airship can carry.

Even with standard atmospheric conditions it is difficult to compare ships of different types or makes because the data is not referred to a common basis. To compare the standard type of data available will prove to be misleading in a great many cases, especially if use is made of them by some one not thoroughly acquainted with this highly specialized branch of engineering.

In order to make the above-named characteristics of use for comparative purposes, each absolute quantity must be related to some other known quantity of equal dimension in order that nondimensional values will be obtained. The conditions for the balance of forces on the mechanically propelled airship suggest themselves as a suitable form of relation.

As the propelling force is counterbalanced by the resistance of the hull and its accessories, the speed at which an ariship of given size can be driven by the horsepower installed depends on the efficiency of conversion of that power available at the crank shaft into useful thrust and on the quality of the airship with regard to drag. This quality is affected only by the external form of the ship

and may be conveniently expressed by the drag coefficient, which like the efficiency of conversion of power is nondimensional. If put into mathematical form the forces acting on an airship in motion may be written as follows:

Air screw thrust in kilograms.

$$P-75E \times N/v$$

Resistance in kilograms.

$$W-D\text{-}c \times Y/g \times J2/3 \times v2$$

where v is the velocity of the airship in meters per second.

N is the total horsepower available at the crank shaft.

E is the efficiency of the air screw and the transmission gear.

J is the volume of the airship in cubic meters.

D–c is the drag coefficient of the hull and accessories.

As the forces P and W must be in equilibrium, the above equation may be reduced to the following:

$$E/D\text{-}c-Y/g \times J2/3 \times v3/75N$$

which represents the efficiency of propulsion. It shows the degree of perfection which the air screws and gears as well as the external form of the airship has attained and also therefore serves as a common measure from the aerodynamic point of view for all types and sizes of airships.

The disposable lift, that is the proportion of the total lift which is available for fuel and oil, ballast, stores, crew, passengers, mail, and freight, after allowing for all structural weights and machines, is determined by the magnitude of these dead weights and by the normal lifting power of the gas which gives the ship its buoyancy.

If "A" is the total lift of the ship for some specified atmospheric condition, and "G" the total dead weight, while "Q" is the useful load, then A minus G equals Q. The efficiency of structural design may be expressed as the ratio of disposable lift to dead weight:

$$y=Q/G=A/Q-1$$

which is called the *lifting efficiency*.

It can be used to illustrate the comparative degree of efficiency to which the structural design and the disposition of materials has been developed in different types and makes of airships of similar size and speed and of similar requirements. When comparing airships of different size and speed and equipped for different kinds of service, due consideration must be taken of the fact that in ships of similar design, structural dead weight is consuming smaller portions of the total lift as size increases and speed decreases, and that the weight allowed for accommodation of the paying load depends very much on the kind of load to be carried and in passenger ships on the margin of comfort to be provided.

By a somewhat arbitrary combination, namely, by forming the product of the values representing the efficiency of propulsion and the lifting efficiency, a third expression is obtained:

$$L=E/Dc \times t$$

This shows the qualities of an airship from both the aerodynamic and structural point of view.

This data was prepared by P. Jaray and furnished by Doctor Eckner of the Zeppelin Co.

Comparative chart of contents, velocity, and load of various representative Zeppelin airships.

Type.	Gas content (cubic meters).	Velocity.		Useful load.	Useful load.
		Meters per second.	Miles per hour.		
LZ-7	19,300	16.7	37.3	6.8	30.3
LZ-120	20,000	36.8	82	10.0	43.0
LZ-14	22,470	21.2	47.4	9.4	36.0
LZ-26	25,000	22.2	49.5	12.2	42.0
LZ-38	31,000	27	60.3	16.2	43.7
LZ-100	36,000	31.8	71	40.0	61.3
LZ-102	68,500	28.6	64	52.1	65.4
Design 301	[1] 70,000	35.5	79.3	42.0	[2] 51.7
Design 275	[1] 100,000	37.5	84	65.0	[2] 55.9
Design 296	[1] 135,000	33.3	74.5	90.4	[2] 57.6

[1] Estimated.
[2] These ships are passenger carriers with large cabins.

Design 301 is United States estimate; 296 is estimate for Spain, Argentine route.

COMPARISON OF DIRIGIBLES.

Figures 2 and 3 are two charts. Figure 2 shows the greater values of the Zeppelin when compared with the Schuttelanz *SL-22*, the English rigids *R-33*, *R-36*, and *R-80*, or the four nonrigids which are given in the bottom figure *B-NS*, *T-34*, *PL-27*, *T-2*. B is the United States blimp and PL, the Parceval. Figure 3 shows proposed and altered cabin for the United States ship (design 301), whose contents are to be about 70,000 cubic meters.

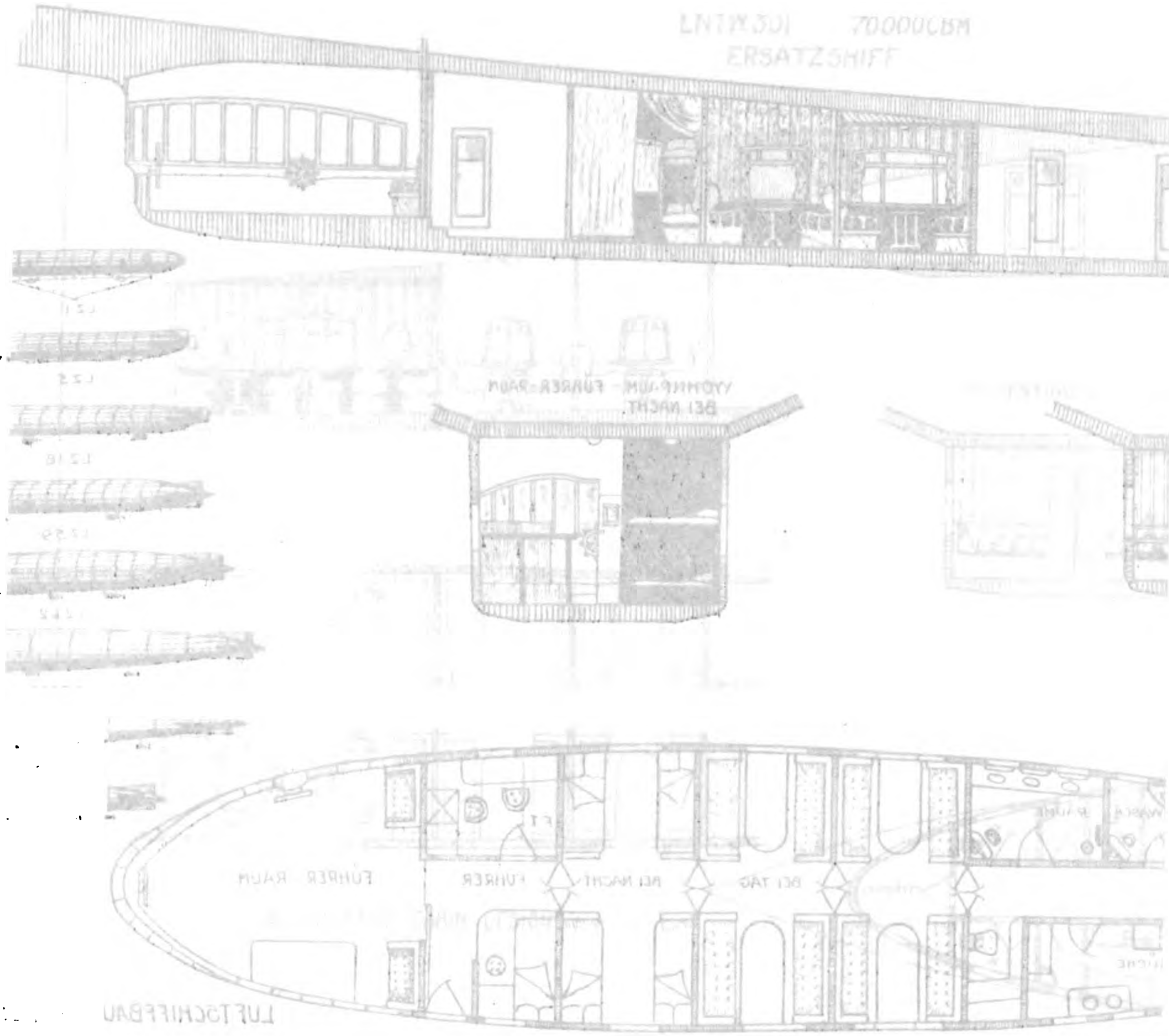
The charts are self-explanatory and show the latest German, Italian, British, French, and American rigid and nonrigid ships.

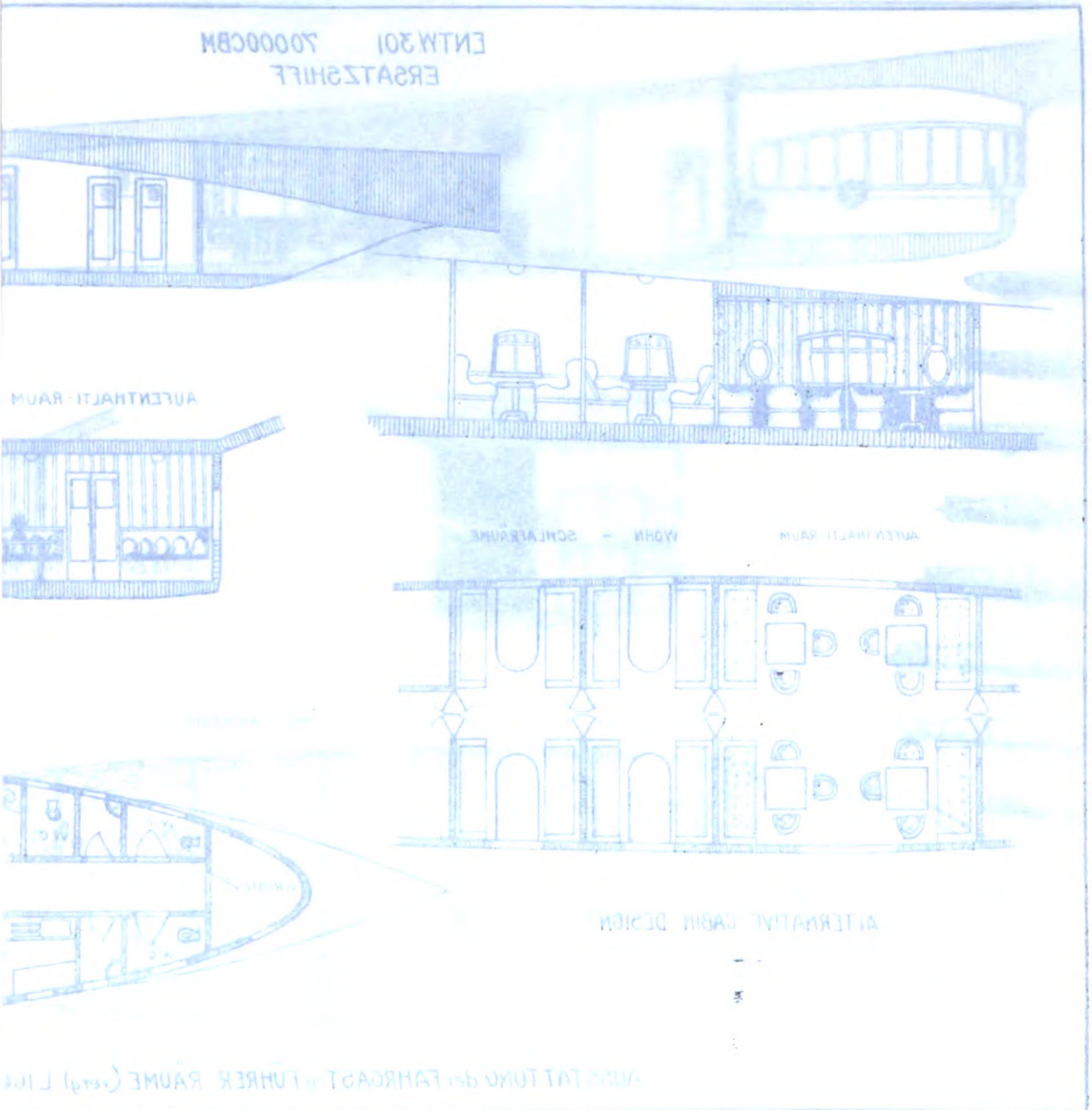
ZEPPELIN-DORNIER CO.

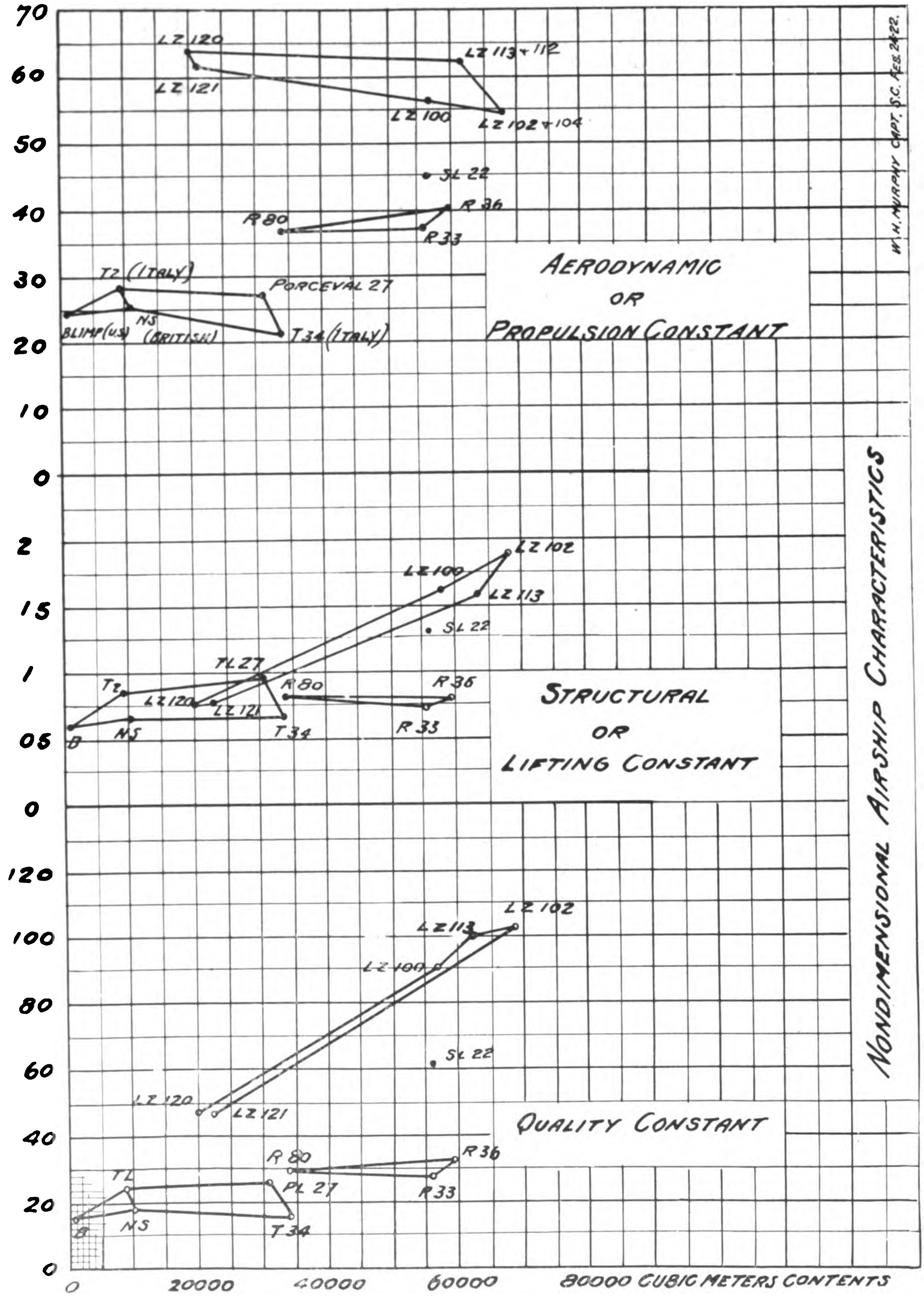
The Zeppelin-Dornier Co. is located at Friedrichshafen, and Mr. Dornier had been placed in absolute charge of designs and construction of all-metal heavier-than-air work for the Zeppelin Co. Doctor Rohrbach was formerly with the Zeppelin Co. and had charge of heavier-than-air all-metal design work at their Staaken plant outside of Berlin, but he has since severed connections to associate himself with Doctor Rumpler. There is no necessity for describing the older types of Dornier machines that were built prior to 1918. They were principally of the flying boat, monoplane type.

One of the later types developed in 1918, called the *D-1*, a single-seater pursuit, powered with a 180-B. M. W. engine and constructed of metal throughout, even to the covering of the wings, was a very interesting departure from all-metal airplane construction in Europe. This machine has a spread of 7.8 meters, length over all of 6.4 meters, area of 18.6 square meters, carries a live load of 180 kilograms, and weighs, empty, 690 kilograms.

The wing construction is characteristic of Dornier standard type. It has built-up steel wing spars of high tensile alloy shapes and is trellised in Warren truss fashion with alloy steel shapes. The spar channels are V shape and are joined on the free edges by a channel in common to both edges which is riveted. The webbing truss as heretofore referred to terminates in the spar channels with alloy


LNTW 301 70000CBM
ERSATZSHIFF


ENTW 301 70000CBM
ERSATZSHIFF
WOHN - SCHLAFRÄUME
ALTERNATIV CABIN DESIGN



LZ 120
LZ 113 + 112
LZ 121
LZ 100
LZ 102 + 104
SL 22
R 80
R 36
R 33
T2 (ITALY)
PORCEVAL 27
NS
BLIMP (U.S.)
(BRITISH)
T34 (ITALY)
AERODYNAMIC
OR
PROPULSION CONSTANT
W. H. MURPHY CAPT. S.C. FEB. 24. 22.
NONDIMENSIONAL AIRSHIP CHARACTERISTICS
LZ 102
LZ 100
LZ 113
SL 22
TL 27
T2
R 80
R 36
LZ 120
LZ 121
R 33
NS
T 34
B
STRUCTURAL
OR
LIFTING CONSTANT
LZ 102
LZ 113
LZ 100
SL 22
LZ 120
LZ 121
QUALITY CONSTANT
R 80
R 36
TL
PL 27
R 33
B
NS
T 34
70
60
50
40
30
20
10
0
2
15
1
05
0
120
100
80
60
40
20
0
0
20000
40000
60000
80000 CUBIC METERS CONTENTS

FIG. 2.

steel gusset plates. The whole wing is covered with duralumin sheets which are joined together in conventional steel roofing fashion at the edges by a U-shaped duralumin strip which overlaps the flat duralumin covered edges and is riveted thereto. The ailerons are attached to the top wing only. There is an absence of interplane struts, which to all appearances gives the machine a questionable appearance from a standpoint of structural resistance to deformation under the heavily stressed conditions of flight in nose dive or sharp maneuvering.

Landing gear struts are built up to duralumin streamline shapes which are bolted at the root to the fuselage shell proper. The main gasoline tank is suspended underneath the fuselage. The fuselage is built up of duralumin channel longerons and channel annular ribs with several longitudinal duralumin channel stringers which are all riveted to flat duralumin sheets which form the covering of the fuselage. It is analogous in principle to standard boat hull construction and seems a fair manufacturing proposition from all appearances. The fin is built integral with the fuselage.

The ribs of all the surfaces, including wings, movable surfaces, and fixed surfaces, are a flat duralumin sheet with circular lightening holes that are flanged at the edges to give them their proper degree of stiffness. This machine has a Junker type nose radiator. The machine is really a forerunner of the modern Dornier interpretation of all-metal construction which has been followed in practically all the later models. He has developed a different wing construction, however, and has used it in some models.

DO. G1, 1920—TWO-ENGINE DORNIER PASSENGER AIRPLANE.

Characteristics of this job are as follows:

- Length, over all: 12.20 meters.
- Span: 21 meters.
- Chord: 4 meters.
- Maximum height: 3.33 meters.
- Wing area: 80 square meters.
- Engines: 2 B. M. W., 185 horsepower, with tractor propellers.
- Fuel required, throttle wide open—
  - Gasoline: 60 gallons.
  - Oil: 4 gallons.
- Fuel required, at normal speed—
  - Gasoline: 60 gallons.
  - Oil: 4 gallons.
- Weight, empty: 23.50 kilograms.
- Weight, loaded, including cooling water and oil: 34.50 kilograms.
- Maximum speed: 180 kilometers per hour.
- Average traveling speed: 150 kilometers per hour.
- Maximum altitude, fully loaded: 6,000 meters.

This machine is a monoplane without flying wires, and like all the other Dornier machines is constructed of metal throughout. All vital parts are of high-grade steel, while the less important structural parts are of duralumin. The wings are covered with easily detachable sheets of duralumin. If desired, however, fabric may be used for the wing covering, in which case the carrying capacity of the machine is increased by 180 kilograms. The construction of the wings is somewhat different from the conventional Dornier type construction. The spars are of the regular high alloy steel construction, but the regular duralumin ribs have been dispensed with in favor of twin web duralumin box ribs situated about 75 per cent of the chord length apart and maintaining rigidity by stiffened duralumin wing covering through the use of duralumin channel stringers in a span sense. The covering is divided into sections between these box ribs and, of course, is fastened at these box rib sections in the usual Dornier way. It is understood that all these fastenings are external and in any case, if it is necessary, the covering can be very readily removed. The wing is absolutely devoid of internal bracing.

Special care has been taken, as is evidenced in the power plant installation, to secure accessibility to all the pipes and the ignition system. As the motors are situated one on either side of the main fuselage, the installation lends itself very well to accessibility. The engine beds extend from a small fuselage wing butt truss which terminates at the motor mounting extremity with landing gears underneath.

The pilot is located immediately ahead of the main wing in the nose of the fuselage and the passenger or bomb compartments are located immediately back of the pilot under the main wing. The propellers have been arranged well forward and are placed in a staggered position so in case of one propeller breaking no danger will occur either to the body, to the wings of the machine, or to the other propeller. The chassis of the machine is designed as a rigid frame. When landing, the impact of the machine is neutralized immediately. If, during emergency landing on rough ground, the machine should turn over on its nose, the passengers are safeguarded as much as possible from injury due to the fact that the motors would be first to hit the ground and thus absorb most of the shock of impact. The heaviest weights are neutralized before the tail of the machine could come in contact with the ground.

The passenger cabin is separated from the pilot cabin by the luggage room and is situated in the part of the machine which offers the best security. Considerable attention has been devoted to the design of gasoline and oil stores. In order to minimize the danger of fire, the gasoline is stored outside of the body of the machine so that the gases can not penetrate into the cabin, and gasoline from leaky tanks can not run over the engines in case of bad landings.

There are no flying wires or braces and apparently the strength and rigidity of the whole job could be assumed as being quite safe. The propeller tip circles come close to one another, due to the fact that the fuselage has been cut off short. This allows the motors to be brought in closer together, and the extent of the dangerous thrust couple that would otherwise be prevalent in a convential job is minimized. Only one of these machines has been built, and the Allies, namely, France, Italy, and England, have divided up all the parts of the machine in three groups and are going to send them to their respective countries for study by their engineers.

DORNIER FLYING BOATS.

Mr. Dornier's flying boat design and construction are characterized by his lateral displacement fins that project out from the sides of the hull on all of his types. This obviates the necessity for wing tip floats, but, according to certain authorities who have witnessed the Dornier seaplanes getting off of rough water, it is very difficult to control them owing to the resistance of these displacement fins with the rough sea and the difficulty of maintaining lateral and directional control.

Mr. Dornier's duralumin floats are of very simple construction and follow quite well the conventional float type of construction with duralumin channel ribs and stringers in place of the conventional wooden ribs and stringers in ordinary wooden floats. The decking, sides, and bottom are entirely made of flat strips of duralumin, stiffened up with duralumin channel stringers. Mr. Dornier's style of all-metal construction seems to be very reasonable and logical throughout in the practical application of his idea. It presents no difficulty from a construction standpoint to any organization equipped and schooled in performing metal work.

SINGLE-ENGINE DORNIER PASSENGER AIRPLANE, COMET TYPE DO. C III, 1922.

The principal dimensions and characteristics are:

- Length, over all: 70.2 meters.
- Span: 17 meters.
- Chord: 3 meters.
- Maximum height: 2.7 meters.
- Wing area: 47 square meters.
- Engine, B. M. W., with tractor propeller: 185 horsepower.
- Fuel consumption—
  - With full speed—
    - Gasoline: 39 kilograms.
    - Oil: 2 kilograms.
  - With average speed—
    - Gasoline: 30 kilograms.
    - Oil: 2 kilograms.
- Weight, empty, including oil and cooling water: 1,250 kilograms.
- Weight, loaded, maximum: 2,000 kilograms.
- Maximum speed: 170 kilometers per hour.
- Average speed: 130 kilometers per hour.
- Maximum altitude with full load: about 5,000 meters.

With a different type of engine the performance of the machine will be varied. The machine is a monoplane without flying wires or braces, and like any other Dornier flying machine is constructed of metal throughout. All vital parts are of high-grade steel, while the body and other parts subjected to minor stresses are of duralumin. The wings are covered with removable duralumin sheets. If desired, fabric may be used for wing covering, whereby the carrying capacity of the machine is increased by about 80 kilograms.

The engine is easily accessible. Adjacent to the engine compartment, but separated by a partition, the saloon has been arranged, having accommodation for six passengers. This saloon may be boarded from the ground without the aid of a ladder. It is provided with every luxury which one would expect to find in a high-class touring car. The panoramic view to both sides is entirely unobstructed. Ample space for luggage has been provided. The pilot seat is forward of the cabin. He can overlook the entire engine.

Special attention has been devoted to the arrangement of the gasoline and oil storage. In order to reduce the danger from any fire, the gasoline tanks have been placed outside of the hull, so that gases can not penetrate into the interior of the machine. Any ignition of the gasoline tanks in case of carburetor fires is also provided against.

The construction of the machine is very plain and simple. There are no flying wires or braces. The factor of safety in the various parts of the machine has been assumed very high, and the entire machine is designed stout and square as possible. The average loading on the wings is low. Under full load it amounts to only 39 kilograms per square meter. The result is a short run on the ground for getting off and a low landing speed.

The landing gear is designed in an extremely simple fashion with a view to reducing the air resistance to a minimum, at the same time insuring greatest strength.

With a load of six passengers the machine can carry fuel for four hours at a high speed, this representing a range of about 600 kilometers.

The life of all-metal airplanes is very much longer than that of wooden machines. As there are no flying wires the wings will not warp. All parts are easily accessible and the covering of the wings is easily removable.

ZEPPELIN STAAKEN PLANES.

The Zeppelin Staaken plane is powered with 400-horsepower B. M. W. engines. The motors are installed along the leading edges of the wing. It was inspected at one of the Zeppelin plants just outside of Berlin. This machine has about 100-foot span and about a 13-foot chord. The motor mountings are very unique and of the cantilever type, extending out in truss fashion from the main duralumin box spars. Accessibility to the motors in flight is obtained by the mechanicians crawling out through manhole sections at the stiffening rib stations in these spars. The fuselage is about 10 feet deep at its master section and approximately 5½ feet wide. It is built entirely of duralumin, no steel being employed anywhere.

The landing gear is of the single, shock-absorbing leg and lateral stiffening V type, with two wheels on each side. The shock-absorbing leg terminates in the spar of the main wing.

The covering of the wings is entirely of duralumin. This machine is very much overweight in its construction and has a very high landing speed as a result. It is the first representative type, however, of a large, all-metal, internally braced monoplane and the lesson of the application of detail and assembly ideas has been far-reaching and valuable to other constructors. The wing construction, however, is entirely too expensive and too difficult as a manufacturing proposition.

Gasoline tanks are located toward the trailing edge of the wings and back of each power plant.

Another interesting Zeppelin Staaken plane is a smaller monoplane powered with 220-horsepower engines mounted on the leading edge. The arrangements are for two pilots

and six passengers. The useful load is about 2,200 pounds and it has a high speed of 110 miles an hour. It has a wing spread of 58 feet. Its radius of action is 400 miles. This machine was not allowed to be completed by the Allies, but it represents a very interesting all-metal construction, with characteristic Staaken single box spar principles instead of the conventional two-spar system in other machines.

Characteristics:

- Span: 31 meters.
- Total surface: 106 square meters.
- Area of aileron: 33.80 meters.
- Total length: 16.5 meters.
- Total height: 3.30 meters.
- Width of fuselage: 1.60 meters.
- Weight, empty: 5,500 kilograms.
- Total weight: 8,000 kilograms.
- Useful load: 2,500 kilograms.
- Power plant: 4 Maybach motors.

This machine in reality was 500 kilograms heavier than the original estimate. It has a high speed of 200 kilometers per hour.

JUNKERS CO.

Aeronautical activities at the Junkers plant, located at Dessau, have been greatly curtailed by the Interallied Control Commission. However, Doctor Junkers is endeavoring to derive commercial revenue through the development of duralumin rowboats, duralumin floats, Diesel engines, gas engines, stoves, kitchen ware, trunks, etc. He is pursuing aeronautical studies and carrying out wind-tunnel tests on various new designs. He intends to keep his organization intact, especially his experienced personnel, by turning over to them the construction of duralumin ware, which gives them an opportunity to keep in practice in the working with duralumin.

Doctor Junkers is designing a 700-horsepower aeronautical engine which is a radical departure from any orthodox type, the characteristics of which, however, were not divulged. Doctor Junkers is keeping it a secret until the motor has been perfected and has had satisfactory tests.

Doctor Junkers has a museum room in his plant in Dessau which contains all the milestones and physical stages of metal construction leading up to his present type. He has been thoroughly scientific and painstaking in the development of his all-metal construction. He has followed out his work logically with full knowledge of the properties of metals and has conducted exhaustive tests and experiments so that at the present time he is probably the best informed man on duralumin in the world. His advanced interpretation of all-duralumin construction, as is evidenced in his latest four-motored, internally braced monoplane, is a decided advance in the construction of large airplanes.

At present there are about 20 of the so-called JL–6 type of passenger-carrying Junkers monoplanes in the factory about 90 per cent completed. Authority to dispose of these machines has also been withheld by the Interallied Control Commission. Doctor Junkers designed and partially constructed a large, internally braced monoplane for four engines, either Mercedes, B. M. W., Maybach, or Liberty. The machine is capable of flying with its full flying load of 9,000 kilograms with three motors. With a flight load of approximately 7,000 kilograms the machine is capable of traveling with two motors.

The wings are of the characteristic Junkers tubular spar construction with plumber union type, screwed wing attachment fittings. However, instead of attaching the wings to nine spars as in the conventional JL–6 type, the wing proper, even though it is of the multiple spar type, is really trussed in the planes of the front and rear spars proper. The top and bottom spar flanges, so to speak, are made of duralumin tubes with cross-flange bracing of duralumin tubing. The whole wing is covered with corrugated duralumin covering. The machine has been designed for passenger carrying, but could be changed to a military load-carrying type if necessary. The fuselage structure is quite a departure from his conventional JL–6 fuselage type. It is triangular in sections and the aft end is detachable at the trailing edge of the wing. The truss is of the three-longeron type of duralumin tubes with Junkers screwed longeron joints. It is very easy to construct, maintain, and repair.

The landing gear is of the two-wheel type with shock absorbers in the leg of each V with practically the same principle as in the JL–6. The landing gear axle is hinged to the bottom of the fuselage. The motor nacelles stick out farther than the fuselage nose, thus obviating the danger, in case of a nose over, of bringing the fuselage in contact with the ground first. The ailerons and elevators are counterbalanced. There are three fixed fins and three rudders. Full detailed description will be sent to the engineering division at McCook Field.

A later projected model is of the twin-fuselage, four-motor, all-metal, monoplane type. This machine is to be powered with four 700-horsepower Junkers engines. The landing gear of this type is quite unique, inasmuch as the wheels and shock-absorbing units are entirely housed in the fuselage structure proper and the main wheels are located directly under the center of gravity of the machine. However, in order to obviate the danger of nosing over, which might be manifested with the wheels located so far back, two auxiliary wheels have been placed on the forward part of the fuselage beneath the nose forward of the center of gravity. This machine has a span of approximately 190 feet and the main chord of 35 feet, giving camber depth of wing of approximately 6 feet. From this it can be readily seen how easily adapted this wing is for carrying of bombs, fuel, or personnel. It represents the best evidence of a streamlined bombardment machine that has been projected in Europe to date.

MAYBACH MOTOR COMPANY.

The Maybach Motor Co. is situated in Frederichshafen. At present they are not engaged in any aircraft-motor work, but are devoting their energies to the design and construction of motor cars. Mr. Maybach stated his preference for 12-cylinder dirigible engines, and according to information he has designed one which he will build at the first opportunity.

The Maybach 6-cylinder war-time dirigible water-cooled power plant is conceded by French engineers and Italian authorities to be the best dirigible engine developed in the world to date. Characteristics of this engine are included in the Maybach handbook on this type, which has been obtained for our engineering division.

REPORT ON B. M. W. MOTOR.

Mr. Stephan, chief engineer of the Dutch Air Service, made an exhaustive study of the Fokker airplanes equipped with the B. M. W. motor. As a supplement to this report, he attached a study on the B. M. W. motor which is considered worth while.

His study is quoted in its entirety, as the B. M. W. was one of the most extensively used motors in Germany.

Motor type.—The 185-horsepower B. M. W. high-altitude motor (200-horsepower Bayern motor) is well known and needs no description. Perhaps some interest will be attached to the service results with these motors.

Overhaul routine.—In the Dutch Air Service the rule for these motors is: Overhaul after 80 flying hours, liable to an extension, after inspection by the controlling engineer, of 20 hours, giving 100 hours absolute maximum.

The overhaul is a complete one, not a top overhaul.

Some of the motors have had four overhauls now and are near their fifth.

With good care and plenty of spare parts to be used at overhauls it will be possible to prolong their life as reliable motors for quite an appreciable period.

As yet no definite conclusions as to their ultimate life have been reached.

Difference of make.—The Dutch Air Service received two series of B. M. W. motors. Part of them were from the original works (Bayerische Motoren Worke, Munchen), the others had been built in license at the Opel Motorworke (Busselsheim). Apart from the construction of the connecting rods, the cam shaft, valve timing, and some minor details, the construction of both engines is identical. The workmanship and finish of the original B. M. W., however, is far better than that of the Opel-B. M. W. Some of the difficulties which were experienced with these motors appeared only with the Opel-B. M. W. and not with the original B. M. W., while other difficulties of which both types suffered generally appeared earlier in the Opel-B. M. W. than in the original B. M. W. The original B. M. W. motor is superior in every respect to the Opel-license-B. M. W. motor.

Service results.—The exceedingly high compression ratio of these motors occasioned some trouble in the first service period, during which ordinary petrol (gasoline) was used. Although the high-compression ratio (6.55:1) does not give rise to its normally equivalent end pressure, as the high-altitude carburetor does not permit full admission at low altitudes and the gas is thus throttled to a large extent at low-altitude full-power runs, it was found that with petrol as fuel the compression was still too high. No type of spark plug could withstand the abnormally vehement explosions.

Ricardo's well-known experiments on various fuels for aviation engines formed an inducement to change the fuel for one with a high "toluene value." A mixture of benzol and petrol in proportion of 60:40, using benzol with a high toluene percentage gave very good results and was adopted as a standard fuel.

The physical properties of the benzol used were as follows:

Sp. W.=0.86.
Freezing point: From −20° C. to −35° C.
Distillation range: From 80 or 85° C. to 110 or 120° C. for 95 per cent. (About 60 per cent beneath 100° C.)

No compression troubles occurred since then.

The ignition in these motors is by means of two Bosch Z. H. 6–'14 magnetos which are a special lightened type of aviation magneto. These proved inadequate. In the Dutch Air Service the normal Bosch Z. H. 6 magneto is mounted instead.

Apart from this it was found that the magneto mounting was badly designed so that another type of mount was substituted.

Of the different failures and other difficulties observed with these motors perhaps the most interesting are cracks in the cylinder flanges.

In the Opel-B. M. W. motor the corner between this flange and the cylinder wall is not rounded off sufficiently, the radius of the fillet being practically nil.

There is nothing remarkable in the fact that such a faulty form leads to fractures, but it is certainly remarkable that in a factory with the experience of the Opel Works such a source of failure can pass unobserved in a complete series of motors.

It is worth note that the fractures occur specially in the first and sixth cylinders, these being the cylinders which get most of the vibration. The cam shaft fixes the other cylinders. The failures are pure fatigue fractures.

The pistons and gudgeon pins are a further source of trouble. Incorporated in the aluminum pistons are cast-iron bushes (the gudgeon-pin housing being cast integral with the piston) in which the gudgeon pin rests. At the slightest amount of play between gudgeon pin and cast-iron bush, these bushes work loose in the piston bosses, and as it is impossible to change these bushes this is a great drawback.

It was necessary to keep a large amount of specially made gudgeon pins in stock with a diameter one-tenth of a millimeter bigger than the original ones. When at an overhaul gudgeon pins are found to fit too loosely in their bushes, these are ground to measure for new pins to be fitted. Possibly in the long run it will be necessary to repeat this system of replacement by slightly bigger pins.

In a similar manner an analogous trouble with the floating bushes of the connecting rod is overcome by keeping in stock specially made bushes with three-tenths of a millimeter more external diameter.

Far too much disparity was found to exist between the pistons of the whole series to permit of complete interchangeability. A strict selection must be made so that the amount of piston play is correct.

The valve mechanism has not given much trouble. Often cam rollers must be replaced owing to inequal wear or play in the roller axles. The rocking lever axles develop play in their bearings, which are simply reamed in the upper and lower half of the cam-shaft covers, of which the lower half is forged steel, while the top cover is aluminum.

In service this necessitates replacement of these covers, as adjustment of these bearings is limited by the amount of room between rocking lever and top of cover.

Sometimes valves guides had to be renewed.

The very peculiar valve timing of the Opel-B. M. W., differing from that of the original B. M. W., is worthy of note.

Whereas the original B. M. W. has approximately:

Inlet opens 5° E.
Inlet closes 37.5° L.
Exhaust opens 52° E.
Exhaust closes 19.5° L.

with individual differences.

The Opel-B. M. W. shows the following setting:

Inlet opens 14° E.
Inlet closes 63° L.
Exhaust opens 55° E.
Exhaust closes 25° L.

with large individual differences.

This extraordinary valve timing reduces still further the already low fuel consumption so that with these motors a fuel consumption of 180 grams per metric horsepower, equal to 0.4 pound per horsepower at full-power ground runs, is regularly obtained. The maximum power output is also slightly reduced as against that of the original B. M. W., but not in the same proportion.

The oiling system gave some trouble with the cam shaft lubrication. This is taken from the front crank shaft journal bearing through an extremely small hole in a nipple and was often insufficient. After changing this by taking the oil supply for the cam shaft direct from the main oil lead in the center through a calibrated jet in a nipple no further difficulties were experienced.

Defects in the oil pumps occur occasionally.

In the cooling system some difficulty is encountered by leaky water pumps. It is often necessary to change the bronze bearing of the pump shaft, especially those directly behind the vane. The water jackets of the cylinders sometimes spring leaks. In the original construction the oil tank was suspended from the cylinders by fixing it to bosses welded on the water jackets, and this frequently occasioned leaks. After changing the suspension of the oil tanks the frequency of water-jacket leaks has been greatly reduced.

The carburetor is rather sensitive for changes in fuel, but is exceedingly good. Attention must be paid to securing the jets, which are apt to get astray. Renewal of the axles of the float chamber rocking levers is often needed.

Care must be taken that the float room cover is well in place.

Renewal of the chief bevel wheel on the crank shaft, owing to its working loose on the key and developing hair cracks, was sometimes necessary, and a good deal of attention must be paid to the vertical transmission shaft. The ball bearings of this shaft often work loose in their housing, a difficulty which is remedied by fitting bronze cages.

Conclusion.—Notwithstanding these difficulties the general impression is that the motor is a very fine specimen of what Germany could produce at the end of the war. It is purely a war motor of sound design but suffering from a few minor faults, partly attributable to wartime material and partly to design, but all of them of small importance. The B. M. W. is a high-altitude motor "par excellence," and should be used as such, and is, therefore, not a motor to be recommended for commercial traffic purposes.

In this respect it may be of interest to note that the B. M. W. motors which are used for the school machines (C–I with dual controls), referred to in the report on the Fokker airplanes, which are never used at high altitudes, have had their compression ratio lowered by 3 millimeter rings under the cylinders.

HOLLAND.

FOKKER AIRPLANES.

The only aeronautical designing and engineering plant in Holland is the Fokker Co. Mr. Fokker has reestablished himself with the Dutch Government and has procured adequate facilities for experimental and development work. In treating Fokker airplanes a brief description will be given of the various types in comparison with the well-known D–VII and this will be supplemented by the very complete report of the Dutch Air Service stating what their experience has been with the standard Fokker type planes through 11,000 hours of flying.

Fokker types are as follows:

(1) Fokker D–VIII: 130-horsepower Oberursl rotary engine pursuit monoplane.

(2) Fokker D–VII: Pursuit biplane.

(3) Fokker F–III: Commercial internally braced monoplane, single-engine job, 260-horsepower engine, carrying 5 people.

(4) Fokker F–IV: Internally braced monoplane with Liberty engine, carrying 10 people.

(5) Fokker V–XL: Internally braced, 300-horsepower Hispano monoplane, armored and unarmored.

(6) Fokker United States Navy torpedo seaplane, with Liberty engine, internally braced monoplane type, twin floats.

(7) Fokker two-seater observation, Liberty motored biplane.

(8) New Fokker 300-horsepower Hispano pursuit biplane, internally braced.

The first five machines are very well known to us, as we have procured one of each of these models to date in this country. This obviates the necessity of describing them.

FOKKER UNITED STATES NAVY TORPEDO SEAPLANE.

The Fokker United States Navy torpedo-carrying seaplane is an internally braced monoplane with veneer covered wings. The wings extend out from the bottom of the fuselage in Junker fashion. The wings are built in an integral unit, fastened from underneath with six bolts, as in the characteristic bottom wing fastening of the D–VII type. The wing tips outside the float support stations are removable.

The tail unit and fuselage are of characteristic Fokker type detail construction. All the control surfaces are counterblanced.

This machine is fitted with two Brandenberg type of seaplane floats. These are of all-wood construction, with steel float tubes braced to the lower side of the wing and the fuselage. This machine has been fitted with the Liberty low-compression navy engine.

It weighs, completely loaded, about 5,200 pounds and has been designed to carry a 1,650-pound torpedo.

The machine is representative as to type, and has been very well designed and constructed for visibility and for defensive armament installation. The gunner-observer's cockpit is situated immediately behind and in close proximity with the pilot's cockpit. The observer's cockpit is extended far enough underneath to permit the use of machine-gun fire underneath the fuselage. The Navy will soon receive delivery on this ship.

FOKKER LIBERTY MOTORED OBSERVATION PLANE.

The Fokker Liberty motored two-seater observation plane is really a geometrically similar type to the Fokker D–VII on an enlarged scale. The power plant is equipped with a nose radiator. The oil tank is placed directly in the rear of the engine in the fuselage on a level with the oil pump. The gasoline tanks can be disposed in the fuselage, wings, or landing gear. If the gasoline tank is in the fuselage, it is placed directly in front of the pilot, between him and the engine. The gunner-observer is immediately back of the pilot. The two cockpits are very close together, as in the DH–4B and XB1–A types. The landing gear is of the conventional Fokker welded steel tube type, with the auxiliary gasoline tank built into it.

The fuselage construction is of the conventional Fokker welded steel tube type. It has been very carefully and thoughtfully executed, always having in mind production, ease of maintenance, and accessibility throughout. Provision for the adaptability in both cockpits of military equipment has been very carefully thought out.

The tail unit is practically the same as the D–VII in design, although it is simpler to assemble. Tail skid springs are fitted as a shock-absorbing medium to the tail skid proper.

The bottom wing has about 25 per cent less chord, although of practically the same span as the upper wing. The total area of this machine is approximately 380 square feet. The main wing rigging truss is identical with the D–VII. This machine could be very well adapted, with few modifications, to meet our observation type requirements, and from a standpoint of accessibility, maintenance, and ease of manufacture, it is epecially well suited to our requirements. It is the best machine with Liberty engine that is to be found in Europe.

This machine completely loaded weighs about 4,390 pounds, with useful load of about 1,530 pounds, which includes five hours' fuel supply. By a change in its present cooling system, it could very easily be fitted with a supercharger.

The wings, fuselage, and tail unit of this machine are covered with fabric identically the same as the D–VII.

All control surfaces are counterbalanced.

FOKKER 300 PURSUIT.

The new Fokker 300-horsepower Hispano, single-seater, pursuit is a machine geometrically similar to the Fokker D–VII in its entirety. It will weigh approximately 2,700

pounds fully loaded, and will have an area of about 290 square feet. This machine is now in the course of construction and ought to be completed soon. As it will be delivered to our engineering division, detailed description is unnecessary.

Three days previous to a flight with Mr. Fokker in his new naval torpedo-carrying job he had sawed off about 3 feet of the fuselage stern, thus shortening it by that amount, and had moved the complete empennage forward in the same measure. This was entirely done within three days' time. Mr. Fokker stated that the tail of the machine as originally conceived was too long and that it was not quite as maneuverable fore and aft as he wished to have it. In the following flight he ascertained the degree of maneuverability and control that this disposition of the tail had given the machine and he was entirely satisfied and stated that it had shown a marked improvement. Mr. Fokker's success in building aircraft is largely due to his ability as a pilot and his first-hand knowledge of the desirable characteristics of control and stability in any type concerned. This ability to test any type and to recognize and rectify immediately the control system fault throughout is invaluable. His direct control over his factory and over his business, his large amount of first-hand knowledge and experience with all different types, plus his ability to pilot and test out his own types, gives him a decided advantage over most modern designers.

In a large measure, our own lack of success in the immediate solution of controlability problems has been due to the fact that designers have not ascertained the feel of the machine from a pilot's standpoint, and thus have to engage themselves with empirical values derived from control surface coefficients, averaged up from all the various types in general use, supplemented by the opinions of pilots who have flown their various types.

Unless one flies, this is the only natural method of ascertaining this data because our knowledge of control surface design from a standpoint of scientific aerodynamical data is not reliable enough for practical application and is too involved to give satisfactory results. In other words, our methods in designing control surfaces have been really rule of thumb while Mr. Fokker has used the cut and try system until he procured what he desired.

On the whole, approximately 8,000 Fokker machines have been built to date, and no master criticisms have been made against his type of construction by European designers except in prejudical fashion. These were directly attributable to lack of experience with his methods. The ease with which any or all of his aircraft can be repaired or maintained has never been surpassed by any other type.

The simplicity of the application of his detailed structural ideas throughout all his types eliminates any complicated fittings and has contributed largely toward aiding Mr. Fokker and his organization to bring out new types very quickly.

Mr. Fokker has made trials with the landing gear gasoline tank set on fire and claims to have had very satisfactory results. There was no flame injury to the rest of the machine. He claims that installing the tank in the landing gear has been the most satisfactory method for protecting the pilot and machine in case of fire. Inasmuch as the flame begins at the burning gasoline tank, it will be immediately blown back by the action of the slipstream. It is out at such a distance from any inflammable portion of the aircraft, and is so insulated by cool air stream between the tank and wings or fuselage of the craft, that danger from fire is minimized. Mr. Fokker claims this is a better installation in practice than a detachable gasoline tank.

MAINTENANCE OF FOKKER AIRPLANES IN GENERAL SERVICE.

(Cantilever wing type and welded steel fuselage.)

(Prepared by the chief engineer (technical service) of the Dutch Military Flying Corps. March, 1922.)

DUTCH AIR SERVICE REPORT ON THE FOKKER AIRPLANES.

The chief engineer of the Dutch Air Service promised to prepare and forward a complete report of the performance of the Fokker airplanes used by that country. This report is so interesting that it is given in its entirety.

It is desired to give full credit to P. W. Stephan, chief engineer of the Dutch Air Service, for all data in this section of the report. The report follows.

GENERAL DATA.

In the course of the summer of 1920 (May–September) the two series of Fokker airplanes with which this report deals (D–VII scouts and C–I reconnaissance machines) were delivered to the Dutch Military Flying Corps (Luchtvaartafdeeling).

The construction of these airplanes differs from the more orthodox design in that the wings are of cantilever type, and the whole of the fuselage, the tail planes and rudders, the wing struts and the central wing fittings are constructed of welded steel tubes. The reconnaissance type carries its petrol tanks in the landing chassis.

The mistrust felt in some quarters against cantilever wings in general is so unfounded and denotes such a lack of knowledge of the stresses to be considered that we may regard it as a thing of the past.

Reflections of this kind were not considered when the order for these airplanes was given, but of course the contract stipulated various static tests. The actual strength in all cases (direct wing loading and wing torsion) was far beyond the requirements.

A certain amount of distrust is still felt in many quarters against autogenous steel welding in airplanes, specially when the welded parts come in traction.

In the Dutch Military Flying Corps, however, through a two years' experience with a small series of Fokker D–VIII, Gnome-Oberursel 160-horsepower scouts, which had a fuselage of welded steel tubes, sufficient confidence in this system of fuselage construction has been gained to warrant an order for a larger series of similarly constructed machines. That this confidence was not ill-placed was proven by subsequent events as described in this report.

The types of machines are both well known, the Fokker D–VII being generally much appreciated by pilots (a couple of these machines had been in use at Soesterberg since 1918), while the C–I was a new design brought out

since the armistice and the first two-seater reconnaissance machine designed at the Fokker works. This type had not been built in series and the Dutch Military Flying Force received the first series of these machines.

Both airplanes have the same motor, B. M. W. altitude type, 185 horsepower nominal (B. H. P.: 200 at normal number of revolutions: 1,400 revolutions per minute).

At Soesterberg some of the scouts are equipped with a Mercedes, high-compression, oversized, 180-horsepower motor.

ACTUAL FLYING TIME ON WHICH THIS REPORT IS BASED.

At the moment at which this report is compiled, according to the log books these machines have an actual flying time of 11,000 hours (10,868 hours and 30 minutes).

During this time not a single fatal accident occurred, while only in one instance, caused by stunting at low altitude—injury of a more or less serious character, severe face wounds—resulted to the pilot. (Machine damaged beyond repair.)

Other accidents, though sometimes considerably damaging the machine, did not result in injuries of any seriousness to the occupants. It must be kept in mind that Holland is one of the worst possible countries for forced landings owing to the smallness of the fields and the great number of dikes intersecting them. Nearly all accidents resulting in material damage were caused through landings ending in a ditch.

Of the 11,000 actual flying hours, only 850 hours were flown in scouts (D-VII), these machines being kept in reserve so that only a few of them are used for practice, etc.

The C-I reconnaissance machines, therefore, have had about 10,000 flying hours. Unless stated otherwise, the remarks in this report apply specially to the C-I airplane.

The number of C-I machines in actual use varied from 30 to 35, the remainder being kept in stock or being in course of repair or revision.

The C-I machine with the largest number of flying hours in actual use has 380 hours to its credit (two overhauls).

OVERHAUL ROUTINE.

In the Dutch Military Flying Force every airplane is subject to a complete overhaul in the workshops after 150 actual flying hours. In special cases this period may be lengthened after inspection by the controlling engineer to an absolute maximum of 200 hours, but the rule is revision after 150 hours. On an average every machine makes in this period between overhaul some 230 flights with landings.

For school machines (some of the Fokker C-I machines are equipped with dual control for instructional purposes) the rule is inspection and overhaul after 400 landings or 100 hours. This is liable to a possible extension to 150 hours maximum. On an average these machines have now each some 680 landings to their credit.

GENERAL FLYING SERVICE RESULTS.

Both types of machines have given full satisfaction in a general way. The Fokker D-VII is so well known that no further remarks as to its performance, strength, etc., are needed.

The Fokker C-I has proved itself a fairly good reconnaissance machine. Its speed is rather low, but its lifting power, rate of climb, and general maneuverability are quite sufficient.

Weight, empty: 1,900 pounds.
Contract load—petrol, oil, and military load: 794 pounds.
Maximum speed at ground level with contract load: 110 miles per hour.
Rate of climb fully loaded to 5,000 meters (16,400 feet): 21 minutes.

The ailerons are rather small, making the machines somewhat sluggish in maneuvering. Apart from this, controllability is very good and the machine is light on controls. The C-I stunts well, as does the D-VII, but good rolls and even half rolls are rather difficult to perform with the former.

The petrol tanks in the landing chassis have no disagreeable effect, either in flying or landing. The machine, though easy to land when the pilot is accustomed to it, is rather delicate in landing across wind.

A very good feature of the machine is that it may be stalled with impunity, there being no tendency to slip down on one wing or to nose-dive out of a stall.

In the Dutch Military Flying Force the C-I has been used as a general-purpose machine, being equipped either for camera work (fixed cameras and cinematograph cameras), for artillery observation, or for light bombing.

For bombing purposes some difficulty was encountered with the bulky petrol tanks in the landing chassis which obstructed the view to a large extent. Ultimately this difficulty was overcome by changing the position of the bomb-sight telescope.

The observer's cockpit is not very roomy and the observer, when on general reconnaissance work, is rather cramped between camera, wireless apparatus, etc. There is no accommodation for parachutes.

GENERAL TECHNICAL RESULTS.

In comparisn to other machines the Fokker airplanes have been strikingly successful. Bearing in mind that the C-I as used was a first production, one may say that it showed very few of the troubles generally inherent in a new type.

The only trouble worth mentioning in this respect was given by the undercarriage. Both the chassis itself and the wheels were rather weak. This was specially so for the very hard sand, gravel, and heather surface of the Soesterberg aerodrome. The tanks gave some trouble, too. The landing chassis was altered and reinforced, as described later on, and other wheels were mounted.

The tail skid and its fittings were not sufficiently strong, and the skid should have had some more lateral play, as it occasioned in some cases torsion of the tail where sharp turns on the ground had been made.

An interesting fact is the comparatively large amount of distortion which the steel tube fuselage will take without any externally visible deformation or loosening of wires. Instances occurred where a machine developed a tendency toward tail heaviness without any apparent cause. A careful investigation of the fuselage structure, fixed in a trestle specially designed for the purpose, showed that although all the wires were still in tension

and the fuselage appeared all right, yet the tail plane was as much as 1½ inches out of line. By simply tightening or loosening wires, keeping them all the while in tension, very appreciable deformation can be obtained. Sometimes a vertical shifting of the tail-plane fittings over 2½ inches was obtained.

All fuselages when overhauled are now checked as to their being in line, while the wire tension is noted also.

There are three predominant factors when judging the relative merits of steel tube structures as used in Fokkers against the more orthodox constructional type of trussed fuselages with wooden longerons and wooden struts or wood and ply-wood monocoque fuselages.

In an article in Het Vliegveld of March, 1922, Mr. Takens, technical officer, R. D. N., attached to the military flying corps as works engineer, draws attention to these points:

First. Simplicity of overhaul and repairs.

Second. General accessibility.

Third. Damage done to machine and danger to pilots in crashes.

The steel tube construction scores under all three headings.

First. Nothing could be simpler than the overhaul of a steel fuselage. After stripping it of its fabric the naked structure is open to inspection from all sides.

It is easily cleaned or checked as to its being in line, repainted, and ready for use again. Compare this with the overhaul of a wood and ply-wood fuselage, all soiled and soaked by oil which has weakened the wood and deteriorated the ply wood. Every cross-strut socket and fitting should be inspected, which is only possible by stripping part of the fuselage of its ply-wood covering. In monocoque construction the inspection of the internal structure is even more difficult than in braced girder fuselage construction.

As to the facility of repairs, this will be dealt with later on, but it is certainly better than with most of the ordinary wood construction.

Second. The accessibility of the fuselage structure itself is far better than in most other constructions, but more important still is the engine accessibility which this type of construction affords. This is best illustrated by comparing a Fokker and a DH-9, both without motor cowling, made as accessible as possible. In the Fokker the different cowl sheets, fixed by wing nuts, are taken off without more ado, leaving the engine perfectly free.

Magnetos, oil, and water pump are all of them accessible.

In the other machine it has, first of all, been necessary to remove the air screw in order to get at the front engine cowl, and even then the accessibility, specially of magnetos, oil, and water pump, is not half so good as in the Fokker.

Third. Provided suitable materials are used and the tubes are not brittle, it is quite astonishing to see what distortion in crashes can take place with Fokker fuselages without any direct fracture.

It certainly is no bold assertion when it is stated that when a machine lands in too small a field with full flying speed, completely wrecking its undercarriage in a ditch and turning a somersault, ordinary wooden construction would be reduced to smithereens, while the occupants might reckon themselves lucky if their injuries were only slight.

In all accidents to Fokker machines the cockpits did not suffer. Even in the case in which a pilot lost his way at night and struck the earth in a ground mist during his downward glide before flattening out, thus diving, as it were, right into the very hard airdrome soil, the pilot escaped without a scratch, although the machine was a complete "washout."

In a report of the Dutch National Aeronautical Research Laboratory on tests on the strength of fuselages composed of seamless steel pipes joined by autogenous welding, which will be referred to later on, special attention is drawn to this significant fact, which contributes greatly to the safety of the occupants and which may be ascribed to the large amount of shock absorbed by the deformation of the steel members in the front and bottom of the machine.

From a maintenance viewpoint this fact means, moreover, that the result of even the worst crashes is more or less local, so that repairs are not so extensive as in the case of wooden machines.

This applies also to the wings, whose box spars are of exceptional strength and therefore suffer but little in most crashes.

An observation which affects operation as much as maintenance may be made with reference to the rigging and dismantling of the airplanes. The removal of the wings is done in less than a quarter of an hour. The rigging is an exceedingly simple job and in no way comparable to the rigging of a machine with ordinary wings.

STRUCTURAL MATERIALS.

Not all the materials used in these machines come up to English or American standard specifications. Still they have given ample proof of being satisfactory for the purposes for which they are used.

Without going into a detailed analysis of these materials, some insight into their properties can be gained from the following general data from tests taken with test pieces made out of the finished parts:

Material.	Tensile strength in tons (of 2,240 pounds) per square inch.	Elongation in per cent.
(a) Steel tubes	28.6- 44	13- 7
(b) Sheet steel for lugs, wing fittings, etc	28.6- 31.1	25-10
(c) Steel bolts (high stresses)	60 - 66	8
(d) Other steel bolts	39 - 61.4	15- 8
(e) Steel for turnbuckles or strainers	42 - 57.1	8- 6
(f) Steel wire (bracing wire)	119.3-183.4	7- 3

(a) Although the elongation is rather small, these tubes will take a great deformation. They invariably conform to the compression test.

The autogenous welding of these thin tubes is a job which requires well-trained men; but under the assumption that the work is done by men equal to their task, it is safe to assume that the welded parts are reliable.

The interesting report of the Dutch Aeronautical Research Laboratory concludes: Autogenous welded joints of seamless tubes (oxygen-acetylene welding), if well carried out, are as reliable as other metal joints or con-

nections. When inspecting a cut through a joint, little defects are ever found. When these are not too large in extent and the crystallization of the two parts that meet in the joint is continual, these defects have no appreciable influence on the strength.

The parts of the tube next to the joint are annealed by the heat of the flame. The elastic limit in these parts is lowered, so that deformation begins there.

(b) This material has not given rise to any remarks. The wing fittings of the Fokker are lightened by holes. It was found that in some of the fittings these holes had been punched instead of having been drilled, thus occasioning small hair cracks starting from the punched holes. These fittings were rejected and only drilled ones accepted.

(c) and (d) In a couple of instances small bolts were found too brittle. In all cases these were tail-plane bolts and subject to vibration.

By lightly annealing these bolts the elastic limit could be lowered without impairing the breaking strength to a dangerous degree, thus giving a higher percentage of elongation.

(e) As the test pieces were made out of the finished parts, they were perforce rather small, and the elongation numbers are therefore not quite reliable.

All turnbuckles, however, stood the double-bending test.

The other materials used do not call for comment. The wing construction follows the same lines as that of the D–VII, which has been amply described. The box spars are built up of an upper and bottom laminated beam of rather low-grade fir strips glued together, with webs of birch ply wood, the whole being covered with fabric, doped, and varnished. In between the top and bottom flanges are glued reinforcing wood blocks at different intervals, the whole following the usual Fokker practice. A special note may be made of the exceedingly efficient cold glue used in these airplanes.

In the Dutch Air Service the "Luward" cold glue (Schütte-Lanz) is used and found to be both excellent and easy to handle.

The ribs are of the same pattern as in the D–VII; the curvature of the leading edge is maintained between the ribs by a veneer layer cut away in triangular fashion and fixed on ribs and spars.

The fabric originally used is a linen fabric of about 80 to 87 pounds per inch strength in warp and weft.

STRUCTURAL COMPONENTS.

Fuselage.—The fuselage is a very sound job as a whole and has given few difficulties.

The only points worth note are:

First. The transverse bulkhead in the motor frame which interconnects the front landing chassis fittings was too weak.

After long service a small ridge developed in the tubes as a result of compression caused by landing shocks.

All machines were therefore altered by additional braces welded to points other than original welds. This form of reinforcement was chosen because the simpler way of using a simple T structure would lead to renewed welding in the middle section of the original construction, which would be weakened thereby.

Second. The cups of the landing chassis fittings were welded in a better fashion than in the original construction because they gave way too quickly.

Third. To obviate the difficulty of the tail skid twisting the frame at the tail, it was found necessary to strengthen this part. It would have been better perhaps to change the place of the tail skid itself, giving it more lateral play, thus taking away the cause of the difficulty, but as this would have necessitated far more work it was thought sufficient to strengthen this part. Two methods were used. The simpler one, consisting of replacing the original 24 by 1 millimeter vertical tube by a 28 by 2.4 millimeter tube, giving not only increased strength against torsion but slightly strengthening the whole tail by the greater circumference that can be directly welded in the V of the main girders. This has proved satisfactory.

A stronger type of tail skid than that originally mounted is now being used also.

An interesting point to be considered is the ease with which major repairs can be carried out. Entire tubes can be replaced and welded in the old fuselage.

The report of the Dutch National Aeronautical Research Laboratory may be quoted as to the best way in which such parts can be welded.

In tensile tests of tubes welded together, with an inner tube as reinforcement, the failure occurred at the outer edge of the inner reinforcing tube, while the total strength of a tube welded in this fashion was greater than that of the original tube. In tests where the inner tube had been fixed by spot welding to the outer tube the failure occurred at a lower maximum stress. Probably this is caused by the annealing action of the welding flame in the neighborhood of the spot weld.

As a rule an inner tube makes the joint more reliable. If it is desired to make it more reliable still by spot welding, then the spot welds must be placed at such a distance from the end of the inner tube that the original material is not weakened by annealing.

In the Dutch Air Service all joints necessary for repairs are made in this fashion, with this restriction, that in cases where the tubes come in tension the butt joint of the outer tubes is made perpendicular to the tube axis, while in cases where the tubes come in compression the joint is made at an angle to the axis. The reason for this is that as failures never occur in the joint but always next to it at a place where the material is annealed by the heat action of the flame, compression struts come in a better condition when this annealed area is not perpendicular to the axis.

If these rules are observed and good welders accustomed to the welding of thin tubes are employed, the repairs are easy and reliable. Of course difficult points require rigid inspection, as was shown in one instance where at the triple joint of the wing-fixing pyramid a hair crack was discovered starting from the small transverse tube. It was found that the joint had been carelessly made and part of the material was burned.

In the Dutch Air Service an inner tube is inserted in the central tube of this pyramid.

It is therefore recommended not to paint such difficult points but to scratch (or lightly sand-blast) them bright and then to varnish them with a transparent varnish.

A point worthy of note in this respect (ease of repairs) is the simplicity of the workshop equipment when compared to what is necessary for the repair of wooden machines. Practically the only equipment needed for fuselage repairs is a good, movable welding plant and a supply of tubes of different sizes. When repairing wooden machines one needs, on the contrary, wood machinery for the machining of struts, longerons, spars, etc., and if no complete stock of fittings, etc., is at hand, the manufacture of these parts is another laborious job, necessitating at least a die press.

These facts are particularly important in time of war when the necessity arises of having repair shops in the field behind the front line. Quite elaborate repairs to steel tube fuselages are then possible, whereas elaborate repairs can not be carried out with wooden fuselage.

TAIL UNIT.

The tail unit, which is identical with that of the D-VII, has not given rise to any trouble. As stated above, a couple of tail-plane bolts failed in use. From then onward all bolts were lightly annealed. As a further safety measure, intended to eliminate dangerous results in case such a fracture might occur again, a simple fitting was designed and mounted on all machines, serving to prevent the doubling-up of part of the tail plane in case of failure of a bolt during flight. It must be pointed out, however, that there has not been an occasion to prove the usefulness of this fitting now that better bolts are used.

LANDING CHASSIS.

The landing gear was the only part of the C-I planes that was inadequate.

As it has a double function, being a landing chassis as well as a frame for carrying the petrol tanks, the different difficulties will be treated separately.

(*a*) *Petrol tanks.*—The general form of this tank is good and the difficulties are only a result of faulty design and improper workmanship. The tank is divided in two by a partition, one part being the chief tank, the other forming an auxiliary tank. As both tanks are pressure tanks, the tank walls are under pressure and the flat partition between the two tanks is not sufficiently strong to withstand pressure combined with shocks from petrol knocking against one side when the other tank is empty. Frequent leaks are the result and, this partition being absolutely inaccessible, repairs are difficult. Of course such leaks only amount to the two tanks serving as one and do not incapacitate the machine.

The soldered seams of the tank are not strong enough. These seams should have been riveted or flanged in some way and then soldered. In the first service period, before the tanks were overhauled, leaks were rather frequent and different forced landings were caused by loss of pressure through leaks, either at the seams or at the joints of the filler cup.

The secondary difficulty was that the ply-wood cover, streamlining the tank, had to be demolished in order to get at the tank for repairs. These streamline fairings were, therefore, altered and made in two parts.

(*b*) *Landing gear.*—The difficulties in this respect started with the axles. These were rather thin (55 by 2.6 millimeters), and as the slots in which the axle moves vertically were not lubricated sufficiently, the axle wore very quickly at the critical point and, in a few instances, gave way. Heavier axles (55 by 5 millimeters) were mounted and more attention was given to lubrication of the axle slots in the chassis.

The next difficulty was that there was too much lateral play of the axle. This caused broken wheels, because the shock-absorber hands came in contact with the wheel spokes. Distance rings were mounted, thus doing away with this difficulty.

The shock-absorber hands, consisting of two short tubes welded to the chassis and ending in a small flange, were too weak. These were reinforced by mounting an inner tube in each.

The wheels were too small and rather weak. They were replaced by bigger and stronger wheels.

The diagonal bracing cables in the chassis were fixed to the struts by small welded lugs. As soon as extra stress came on the cables through hard landings, the small welded lugs were torn out of the strut. The joint itself never failed, but the lug was torn out bodily with the joint and a strip of the tube.

All chassis were altered and reinforced.

Taking everything together, the original landing gear was decidedly too weak and even in its altered form is far from being ideal.

WINGS.

The wings are of astonishing strength, especially in crashes, and are exceedingly simple in repairs. Even in the worst accidents it is an exception to find a broken spar which can not be repaired with very little trouble. If spars show a fracture after a crash, it generally is in the thinnest part of the wing tips and is occasioned by the crushing of the wing tip in striking the earth. Such fractures, which are rare, are easily repaired by making simple splices in the top and bottom beams, staggering the scarfs according to the laminations, and fixing new ply-wood webs over a greater area than that limited by the splice.

The following difficulties were experienced with the wing construction:

The internal bracing is badly designed. The bracing wires attack the spars at their weakest end where there is no strut or compression rib to take the resultant stress. It is obvious that this faulty arrangement leads to spar deflections at the points where the lugs are attached. These deflections were often of the magnitude of 6 millimeters and more.

As this result was discovered at the overhaul when the spars were already deformed, it could not be remedied by simply fitting a strut or compression rib. Therefore a thick three-ply panel reinforced by two triangular glued struts was fixed between the spars at this place.

The designer of the machine proffered the opinion that this internal bracing is not needed as a drift truss, because the wing is strong enough without it, but that it serves more to keep the spars in place during assembling, an assertion which must be taken "cum grano salis."

Though there are no real compression ribs in the drag truss, still there are some double extra strong ribs, intended to serve as compression ribs.

That a better drift bracing is needed is shown also in the behavior of these ribs. In the lower plane the webs of the innermost reinforced ribs have a tendency to buckle up. This has been remedied.

A further point noteworthy in this respect is that the wing spar fittings, especially of the lower wing, develop a little play after long service. This play sometimes amounts to 2 millimeters and is taken up by inserting small flat wedges between fitting and spar.

A quite unimportant alteration made in the Dutch Air Service is the half rib which was put in the wing near the fuselage because the veneer layer in this place suffered too much at the hands (and feet) of mechanics.

It was found that most wings did not need new fabric at their first overhaul. Therefore the fabric is often only loosened at the points needing inspection and then repaired. After this all the paint is removed by a solution that does not attack the dope. The wing is then redoped and repainted with a pigmented dope covering. Treated in this way the fabric can generally stand 300 hours and more. The wing is then completely stripped and covered with new fabric at its second overhaul.

In a few upper wings, for no apparent reason, the fabric at the top was torn loose from a couple of ribs. As this happened only at a place where there is an inspection and entrance hole for the aileron control cables in the lower surface of the wing, possibly an explanation of this occurrence may be found by assuming that through this aperture, giving direct communication between the pressure side (lower surface of the wing) and the suction side (upper surface), the positive air pressure is brought to bear on the inner side of the fabric in the upper wing surface, thus causing a far greater strain on the stitches than is normal. Therefore not only was a better thread used for stitching the fabric to the ribs but two small holes were made in the upper surface near the trailing edge.

DETAILS.

The steering gear is good, though its construction does not come up to the English standard. A commendable feature of the Fokkers is the double aileron control, which should be standard on war machines.

The bearings of the control stick developed play too quickly, therefore these are being changed in the Dutch Air Service, and ball bearings are mounted instead of the original bronze bushes.

The different cockpit fittings (gas and ignition handles, petrol cocks, safety belts, cockpit upholstering, etc.) were more or less of a perfunctory nature, showing that these machines were equipped according to war-time ideas of their time of service. They are quite sufficient for a machine which in the course of a couple of months is either wrecked or superseded by a new type, but for machines intended to serve during a lengthy period in peace time more attention should be given to these details.

The motor cowling, built up of different loose sheets, fixed by winged nuts, is very practical, as stated before, but the interchangeability of these sheets leaves much to be desired. Practically no two cowling sheets and machines have the holes and bolts in the same place. A lot of trouble would have been saved if at the outset more attention had been given to interchangeability.

This remark applies also to petrol tanks, radiators, empennage, interplane struts, etc.

Radiators gave some trouble (leaks) owing to their rigid mounting. When mounted on felt washers very little trouble was experienced with the honeycomb type.

CONCLUSION.

The Fokker C–I, as well as the Fokker D–VII, has given great satisfaction in service.

The different difficulties which were encountered are, all of them, of a minor character and can be remedied with small trouble.

The general impression left by 11,000 flying hours' service is an excellent one.

ENGLAND.

RÉSUMÉ OF BRITISH RESEARCH DEVELOPMENT IN SERVICE AIRCRAFT.

WIND TUNNELS.

One of the striking things noticed in England was the existence of wind tunnels at practically all the important aeronautical manufacturing establishments. As these vary in scale, dimensions, and charcteristics, it is very hard to correlate the data in concrete cases for comparison. The principal purpose of these was to get relative data which would be close enough to show the immediate relative advantages even though they could not be applied by correction factors to accurate full-scale machines.

The tests conducted are further valuable to ascertain conditions of fore-and-aft stability and for getting measurements of relative resistances.

AERODYNAMICS.

A large amount of full-scale work has been done for measuring the full-flight variations of different airfoil sections. The English have used a thrust meter to advanatage in helping to evolve characteristic full-flight data.

Other research work is being carried on at present in the form of increasing controllability of airplanes at low speeds, endeavoring to attain efficient control disposition. Further investigations will be carried out in the near future on the comparison of water-cooled and air-cooled engines from the standpoint of consumption of power for cooling. Cooling with radiators will be compared to direct air-cooled cylinders. The direct merit factor as regards water-cooled versus air-cooled power-plant installation in a hypothetical airplane will be tested to determine the choice from a viewpoint of the total resistance of the machine in each case.

The British research department is investigating the problems of control at low speeds, and the solution of this problem may, in their opinion, give more advantage than the development of wings of high lift.

STABILITY DATA.

A considerable amount of work on stability derivatives for prediction of stability characteristics of aircraft is being done. They desire more practical assumptions for supplying data to airplane designers to aid them to anticpate in advance the stability properties of aircraft.

AIRFOILS.

It has been noteworthy that, with the Handley Page slotted wings, DH-9's have been more efficient and have had greater climbing ability than when fitted with standard wings. The launching run with the Handley Page wing was one-half that of the run when fitted with the ordinary wing.

The model tests on the Alula wing have not shown any exceptional advantage, but the possibilities of large correction factor advantage on full-scale models were being explored. The designer made radical statements as to the fallacy of correction factors that are now being applied from wind tunnel model experiments to full-scale airplanes.

STATIC TESTS.

The assumptions for carrying out the static tests of aircraft and for methods of calculating stress for aircraft structures have been standardized by the Air Ministry and assumptions are followed as in Pippard and Pritchard's Air Ministry Handbook of Strength Calculations.

Of course it is known that the more accurately the loading in flight is done, the lighter the airplane structure can be made and, as heretofore mentioned, full-flight pressure-zone tests have been conducted and are being employed as a guide to the attainment of a more accurate knowledge of the distribution of load and of stress. It has been found to differ quite appreciably from the model pressure tests in smaller scale. Finally, the more exact knowledge of the full-size pressure distribution will certainly give more exact nature of loading and a lighter structure, and give the industry more simplified assumptions which, though not strictly accurate, should in the main be accurate enough for practical use. Furthermore, the British aeronautical structural engineers are engaged in the simplification of accurate calculations for redundant aircraft structural members.

FLIGHT TESTS.

In most of the full-scale flight-test experimental work at the Farnsborough station the investigators were people charged with the solution of flight-test problems, actually carrying out their own flying problems themselves. This is significant when one considers the advantage to the investigator or scientist of getting this first-hand information from full-flight testing himself. Tests are also being conducted in full flight for determining the regions of varying pressure along the wings, along the fuselage, and in the region of the landing gear and tail surfaces.

AILERONS.

Different adaptations of aileron counterbalancing features have been evolved by different manufacturers to correct for and minimize the amount of fatiguing exertion required of the pilot to maneuver the ailerons throughout the operating ranges for lateral control. In one instance, the *DH-34* and *DH-29*, the aileron demultiplying control system of leverage and angular range has been so designed that the high side aileron is moved through a

greater angular range than the low side aileron. This, in combination with the counterbalanced aileron leading edge, offset from the aileron spar proper, allows for lateral control with much less exertion than would normally be required.

The latest Handley Page has the ailerons counterbalanced all along the leading edge in such a way that after obtaining the maximum positive and negative range of aileron control position the leading edge of the aileron counterbalanced portion does not extend beyond the upper or lower limits of the spar section. They claim this is a decided advantage and makes lateral control easier.

ADJUSTABLE TAIL SURFACES.

In large airplanes of the multimotored type different schemes have been adopted for varying the tail settings on the horizontal and vertical surfaces to correct for the longitudinal fore-and-aft trim, due to the variation of load about the normal center of gravity and also for correction of directional control which is ordinarily upset by one motor cutting out, thus making it difficult for the pilot to maintain direction with the flexible rudder control.

In the Bolton & Paul, and most of the other British multimotored types or single-motored types requiring fore-and-aft adjustment, the stabilizer is variable in incidence at the control of the pilot from the cockpit. However, in the Vickers Vimy type, in correcting for one motor cutting out, the rudder bar in the cockpit is offset by a telescopic hand-loading spring arrangement fastening between the rudder bar and floor structure of the airplane so as to neutralize the effort required of the pilot to correct for the uneven thrust couple involved. In the Bolton & Paul type a double-hinged rudder and fin combined is utilized so that the forward hinged portion of the fin part is set in an angular position by means of a handwheel control in the cockpit. The rudder proper is hinged to the aft end of this adjustable fin and is coupled directly to the rudder-bar controls in the cockpit.

METAL CONSTRUCTION.

One of the many problems in connection with alloy steels and nonferrous alloy in England has been the procuring of the best metals for commercial use which have been evolved in laboratory tests.

ALL-METAL PLANES.

The English have been very slow to follow up the trend of metal aircraft development in France and Germany. The Vickers Co., the progenitors and patentees of duralumin, did not have any duralumin experimental aircraft work under way in their factory at Wybridge that could be seen. The only application of metal to aircraft that was noticed there was in the use of high-alloy steel tubing with external steel fittings. The Short Bros. Co. are the only people to have used duralumin to any extent on an airplane in England. Detailed description of their *Silver Streak* will be found under the heading, "Short Bros. all-metal planes." This is a very creditable interpretation of a duralumin fuselage.

The Bolton & Paul Co. are using high-alloy sheet shapes and the Siddeley Co. is using in their all-metal aircraft high-alloy steel tubing and alloy sheet spars and ribs throughout. This is a very expensive wing construction and is very difficult to repair. The fuselage steel tubing idea of structure is fairly well interpreted and makes for a sound structure.

Mr. J. D. North, chief engineer of the Bolton & Paul Co., says duralumin is a washout. Some information is current in English aeronautical circles that duralumin deteriorates with age and loses some of its physical characteristics. However, this should be investigated and traced for authenticity.

Welding has been absolutely discouraged in aircraft construction in England, but this action should not carry much weight, inasmuch as the English have not had any practical experience in the use of welded construction. Their assumptions and conclusions have been entirely theoretical and are prejudiced.

RADIATORS.

A large number of radiators installed on British machines are still of the nose type. However, in the De Haviland, Fairey, Bolton & Paul, and several others, radiator installations have been placed in the partial free air position such as the engine underslung tunnel type with honeycomb core.

The English have been employing very low caliber ratios for their radiator cores and have not attained the ultimate efficiency of a straight core tunnel radiator that would ordinarily be the case if higher caliber ratios of 35 had been employed in these regions of high velocity.

OLEO LANDING GEARS.

One of the latest and most widely applied developments pertaining to airplane landing gears has been that of the Oleo shock-absorbing type and its use by the Bolton & Paul Co., Bristol Airplane Co., De Haviland Airplane Co., Armstrong-Siddeley Airplane Co., Handley Page Co., Vickers Co., Martinsyde Co., etc. The idea, according to the different designers questioned, was to eliminate as far as possible the secondary rebound in airplanes which is prevalent with the rubber shock-absorbing type landing gears. By applying the Oleo dashpot principle in combination with rubber or spring shock absorbers, or in Oleo dashpot fashion alone, the shock is damped more readily. In America there has been no evidence of an Oleo type landing gear. This ought to be one of our next lines of endeavor in experimentation on an airplane such as the Martin, or other serious service types.

PALMER TIRES.

The Palmer Co. has recently developed a new tire for large airplanes requiring large wheels and large diameter tires with a flattened tire casing tread so as to allow a higher resistance of these wheels in going over soft ground. These should be tried out on our Martins.

PURSUIT PLANES.

The 300-horsepower Hispano motor is not being used in England at this time on any of their later types. Their pursuit plane program, now and for the immediate future, will be with machines equipped with the Siddeley Jaguar engines or the Bristol Jupiter engines. Detailed characteristics of the Siddeley Siskin are included in an Admiralty performance report embodied in this report.

OBSERVATION PLANES.

The Bristols equipped with Rolls-Royce engines are still being used by the English for their two-seater work.

NIGHT BOMBARDMENT PLANES.

The Handley Page and Vickers Vimy bombers are on their program for night bombardment purposes. The day bombardment types are still mainly the De Haviland class of aircraft.

TROOP CARRIERS.

An interesting type that the English have been experimenting with and building in small quantities are the Vickers troop carriers. These machines are standard, multimotored, bombardment types, redesigned to carry troops lightly equipped. A similar type is being constructed by the Siddeley Co., having two Napier Lion engines. These ships have been principally evolved for colonial use where troop transportation is a problem. If this type is warranted in our service program, we could follow suit by adapting one of our large bombardment types, with provision made in the fuselage for locating the troop load and their light field equipment, such as rifles, ammunition, food, etc. This type is quite analogous to a large commercial multimotored type. If it were decided to develop this type, it might be advisable to do so as a commercial ship and to study adaptability for this use.

TORPEDO PLANES.

The Blackburn Co. and the Handley Page Co. have been awarded experimental contracts on torpedo-carrying machines. The details of the latest Handley Page torpedo-carrying type have not been divulged, although a Blackburn torpedo-carrying type has been purchased by the United States Navy and is now in this country. Specifications of the Air Ministry torpedo type have been procured and are included in this report.

As a result of the extensive torpedo-carrying airplane experiments that have been carried on by the British it would seem advisable to carry on experiments with the torpedo-carrying type in our service and to evolve a type specification for it, following very closely the specifications advanced by the British.

AMBULANCE PLANES.

They have also evolved in practice an interpretive ambulance type airplane by changing over the standard Vickers Vimy passenger-carrying machine. Specifications for the Air Ministry type airplanes have been included in this report.

Inasmuch as a satisfactory ambulance type airplane has not been built in this country with reference to number of patients carried, equipment, desirable landing speeds, etc., it would seem quite necessary, inasmuch as there is practical use for this type of airplane, that we give it serious consideration in the future. The preliminary consideration should be layout and disposal of the load, with marked facilities for landing in very mediocre fields.

AMPHIBIANS.

English amphibian development has been successful in so far as the application of removable landing gears is concerned. The poor performance, small military load carried, difficulty of handling, poor field of fire, and the low ceiling obtainable, all combine to make them a very undesirable type to develop from a military standpoint. The characteristics of their latest amphibians are approximately as follows:

The Super-Marine, Fairey, Parnell, and Vickers types:

Ceiling, average: About 16,000 feet.
High speed: About 110 miles per hour.

The Super-Marine amphibian is the flying boat type with a Napier Lion engine mounted in overhead fashion. There is a gunner to the rear of the wings in the hull, and one gun is located forward.

The Vickers type is analogous to the Super-Marine type so far as disposition of load and general arrangement is concerned. The blind angles caused by the tail unit and by the main wing structure are considerable. The logginess of the types is very pronounced. They would afford a very easy mark for land pursuit planes in case of war.

The Parnell and Fairey are of the fuselage twin-float biplane seaplane type. These machines offer a better range of gunfire for the rear gunner due to underslung rudder, but, as a whole, they have the same disadvantages of logginess, poor visibility, and very mediocre performance.

LARGE FLYING BOATS.

The British seem to be giving considerable importance to the development of large flying boats by allowing contracts for large multimotored flying boats of the Fairey N-4 type.

Fairey N-4 type flying boat.

The hull of the flying boat is approximately 66 feet in length, including rudders. The lines of the hull are quite similar to the hull of the F-5 flying boat. The hull was built to Air Ministry design and has the following characteristics:

Area of wings: 2,900 square feet.
Area of tail: 350 square feet.
Rudders: 50 square feet.
Fins: 50 square feet.
Elevators: 50 square feet.
Ailerons: 83 square feet.
Span: 139 feet.
Height: 29 feet 6 inches.
Length over all: 66 feet.
Chord: 12 feet 6 inches.
High speed: 105 miles per hour.
Power plant: 4 Rolls-Royce Condor 600-horsepower engines mounted in twin tandem eggs between the wings.
Float displacement with full load: 32,000 pounds.

The hull is not divided into water-tight compartments. The runway extends along the whole interior of the hull. Gasoline tanks are secured in cradles on each side of this runway. It is intended to provide sleeping accommodations for the crew. In the tail two large portholes, one on each side, are provided with water-tight doors so that four machine guns may be mounted there.

Fan-driven Servo motors are installed in the tail for aiding the pilot in controlling the ship.

This machine is situated at the Isle of Grain Naval Air Station and has been developed principally because of the belief in some naval circles that seaworthy flying boats of great range and of large size which can follow the fleet and operate with it wherever it goes, for fleet reconnaissance work, are more practical than other types. They claim that landing on capital ships is impractical and that capital ships in battle formation would not alter their course in order to enable craft to return to them.

Vickers Valentia type, and the large Fairey Atlanta powered with four Rolls-Royce 600-horsepower Condor engines.

Seaworthy tests are being made on these large-type flying boats which weigh as much as 15 tons. Inasmuch as the launching and landing of them is a large task, it is necessary that they be capable of being moored out on the open sea for a considerable length of time.

DECK FLYING.

A considerable number of experiments are being made in flying off and landing on the decks of airplane carriers, with a view to ascertaining and developing shipboard aircraft for open-sea warfare. It is hoped that the development of their amphibians may be the solution to this problem.

Although aircraft equipped with wheels may take off from a capital ship with ease, it was thought that capital ships should carry scouts equipped with skids instead of wheels, taking off from greased troughs and then landing on aircraft carriers. This was Commander Busteed's opinion. It is accomplished by having an attachment fastened on the landing gear for engaging with wires strung forward or aft on the deck of the carrier.

The English ship planes for landing on aircraft carriers are all equipped with a harpoon spring-locking hood device. This hook has a pitch between the hooks of apparently 8 inches to allow for hooking over cables strung fore and aft along the decks of the aircraft carriers. The hook engages with these cables and keeps the plane from swerving off the deck. It is a very simple adaptation, mechanically sound and practical in its application, although it means an increase in head resistance. These harpoon hooks are fastened on the landing-gear axles.

TRAINING PLANES.

The Avro training machine is still the standard English training type, and one of their latest Avros that was formerly powered with rotary engine has been changed over with the Hispano 160-horsepower motor.

The British have a large number of Nieuport Nighthawks that were designed for the ABC nine-cylinder air-cooled engines. This machine is now undergoing tests at Martlesham with the Siddeley Jaguar 350-horsepower, radial, air-cooled engine, in order to adapt this type to their pursuit program. The Siddeley Siskin, however, is a more advanced type, having better maneuverability and climb and equal in speed to the Nieuport Nighthawk.

HELICOPTERS.

Very little enthusiasm is being shown in Great Britain over the possible advent of helicopters. However, the British Air Ministry appreciates the possible advantage to this type for ultimate adaptation, inasmuch as they are contemplating to allow $200,000 as a prize for the development of a helicopter to fulfill certain conditions prescribed by their experts. There is a decided antihelicopter sentiment throughout the entire heavier-than-air industry in England.

Mr. Brennan has designed and built a helicopter at Farnsborough which is being tested in secret. This helicopter, according to claims, has risen from the ground with its own power with 250 pounds weight. The nature of experiments with this type has not been divulged, but it is understood that further flight tests will be made very soon.

ENGINES.

The British are striving to produce a suitable airplane engine that will be absolutely reliable and have a long life between overhauls. These fundamentals they consider are most important for reliability in the operation of aircraft. They are also endeavoring to reduce the fuel consumption in the different aircraft engines. Experiments are being conducted at Farnsborough to determine the relative advantage of fuel injection over the conventional carburetor systems on our present-day internal combustion types. They are also trying to use shale oil in developing Diesel cycle units. Diesel type single-cylinder units are being used in the dynamometer laboratory at Farnsborough. Experiments are also being conducted with alcoholic fuels. Mr. Taylor, the dynamometer engine expert, stated that the advantages of direct injection would be a high-flash point fuel with reduced fire risks, higher compression and efficiency, more economical fuel consumption, a fuel supply independent of pressure heads, reliability not interfered with by dirt in fuel, and the entire elimination of magneto type of ignition.

In certain tests a single air-cooled cylinder that they have developed has given as much as 200 horsepower. They hope that a 1,000-horsepower air-cooled engine will be possible. Such an engine would be desirable with a gear reduction of about 2 to 1 for the propeller.

The results of development tests of the Bristol Jupiter and Siddeley Jaguar engines have convinced the British motor experts of the practicability of design, construction, and operation of light air-cooled engines.

Important consideration should be attached to the pursuit development in Great Britain, particularly as to the type involved, that is, the maneuverable and climbing type with radial air-cooled engines. The Siddeley and Bristol radial, air-cooled engines have passed the Admiralty tests. This type should be studied from a standpoint of adaptation to airplanes for which it would be desirable.

Inasmuch as we have not developed radial air-cooled engines beyond 200 horsepower in this country, it is advisable that we immediately expedite the development of a 400-horsepower type with the limitation of 2 pounds per horsepower in weight, or we should encourage the American manufacturers to procure rights for the Siddeley Jaguar engine and the Bristol Jupiter type. This should be done after exhaustive tests have been made in this country on the experimental Jaguar and Jupiter that we have purchased or will purchase in the near future.

The 450-horsepower Napier Lion engine is being most extensively used in English military and commercial

types. This engine has been fully service tested and proven.

MOTOR MOUNTINGS.

The motor mountings on the more advanced types of airplanes in England are of the cantilever pyramid type. They are built attachable so as to allow for the ultimate and immediate replacement of engines while in commercial or military service.

The fire walls, according to the latest English ideas, should be of the metal-faced, asbestos-core-lined type, and holes that would ordinarily be pierced through the fire walls for allowing the passage of controls, wires, etc., should be minimized to the greatest extent. Where rods or wires absolutely have to be put through the fire wall, it will be necessary to use the gland connection so as to absolutely do away with any chance of flame or gasoline seeping through.

ENGINE MUFFLERS.

A great number of contrivances have been rigged up in England for the muffling of engines. Bolton & Paul Co. has gotten up a partitioned aluminum casting air-cooled exhaust manifold, on the outlet extremity of which is fastened a light steel gauge exhaust manifold extension with a closed end. This pipe is about 3 inches in diameter and about 6 feet long. It is perforated throughout all its length on the outer half, away from the fuselage, with rectangular slots of about 1 inch by one-eighth inch. This apparently helps to dampen out the noises due to the explosion enough to permit communication by word of mouth between pilot and observer. The aluminum exhaust manifold is partitioned with telescopic joints extending between each pair of cylinders in the bank so as to do away with the possibility of cracking and reduce the strains due to cooling. It is cooled by projecting aluminum fins so as to obviate the danger of fire which so often occurs from hot manifolds.

SUPERCHARGERS.

A DH-9 has been fitted with a supercharger which is very similar to our General Electric type. Although results of their tests have not been divulged, it is significant that they claim a practical solution for their type. They also claim to have realized sea level horsepower at very high altitudes. The necessity for variable pitch air screws is just beginning to receive consideration. They have experimental projects for further development.

STARTERS.

Different principles for automatic engine starters have been tried in England. One proposed by Major Norman, formerly of the R. A. F., is constructed by the Bristol Airplane Co. This starter consists of a single-cylinder, light-powered, air-cooled engine and small compressor which forces a pressure mixture into all the respective engine cylinders in time, thus throwing the engine over. This self-starting arrangement takes its gasoline from the main service tank and is not prohibitive in weight, weighing approximately about 45 pounds installed.

The installation that we witnessed was in a DH-4. The small motor was installed directly back of the observer's cockpit and the observer could turn around in his cockpit and turn it over by hand. The starting can be controlled either by the pilot or the observer from the instrument board. Practically all of the English service and commercial airplanes have been equipped with propeller front flange connecting clutch for adaptation to field starting of the airplane from an auto truck portable engine-driven starter.

There are two well-known types of field starters in England; one, the Aircraft Disposals Board Ford motor car starter. It is very practical, very effective, and very well liked at all the airdromes that we visited in England. Another well-known auto starter is the Crossley Motors model. This is a much larger auto unit and has a vertical extension starting tower capable of being regulated in height for starting motors in huge airplanes with the motors high off the ground, such as in the Handley-Page, Vickers Vimy, DH-34, and similar types. Of course, the main disadvantage is the fact that these are external means of starting and really do not solve the integral self-starter installation on aircraft, which has been attempted in the Bristol type.

Personally, it is believed that for home airdromes the idea of a field auto truck starter is sound and deserves attention.

FUEL SYSTEMS.

The trend in commercial aircraft has been to locate separate fuel tanks out and away from the fuselage, either underneath or on top of the upper wing in gravity feed fashion or on top or underneath the lower wing and fed to motor with a fan-driven fuel pump.

With the latest type military aircraft, pressure systems are being avoided and fan-driven Vickers gasoline centrifugal pumps are being installed on most of the machines in conjunction with the gravity auxiliary system.

On multimotored airplanes it is desired as far as possible to have independent fuel supply system for each power plant, working independently or in unison at the control of the pilot. The separate gravity tanks are also at the control of the pilot. In these large multimotored airplanes, auxiliary direct feed hand pumps of large caliber are installed within easy access of the pilot so as to permit filling of the gravity tanks from the main service tanks in case the fan-driven gasoline pump system should fail

FIRE HAZARDS.

A great deal of attention is also being paid to the neutralization and elimination of all existing fire hazards. Toward this end the British have organized fire-prevention committees made up of the most representative engineers to investigate and make recommendations of practical measures to reduce the danger on standard power plant installations and fuel systems. It is desired to evolve a machine as nearly as possible resistant to dangers of fire, whether in the air, on crashing, or running on the ground.

PETRO FLEX.

One practical result so far that helps is a hose connection. Mr. Blaisdell has developed a gas hose called petro flex which seems to stand all tests that is has been put to. The fact that rubber joints in gasoline lines have been a constant hazard in existing fuel systems has lead the Air Ministry to evolve an all-metal coupling, thus making the complete circuit entirely metal.

The fire prevention committee has recommended placing tanks away and out from the fuselage, fastening them on the wings, and thus obviating the danger of leaking gas from the damaged tanks getting into the region of the hot exhaust.

Experiments are also being conducted with Pyrene fire extinguishing systems similar to the Burke system developed at McCook Field.

PROPELLERS.

All possible impetus is being given toward the development of all-metal air-screws because of demands for their adaptation on service colonial type machines in the East, in Mesopotamia, and in Egypt. The employment of wooden propellers of the conventional type has not been satisfactory in these countries. The British are not aware of the advantages of the American Bakelite propeller for this work.

BOMB INSTALLATION.

The trend of bomb installations is to put them under the fuselage. This obviates the large head resistance that would be inherent with exterior wing installation such as was used in the war.

MACHINE-GUN INSTALLATION.

The fixed machine-gun installations are practically all of the exposed type, being placed on a level with the pilot's shoulders. In cases where ammunition required for two fixed machine guns is in the neighborhood of 2,000 rounds, machine guns are staggered in a fore-and-aft sense and the ammunition boxes paced one in front of the other to permit minimum fuselage displacement.

On most of the single-seater machines spade grips are being employed with motor cut-out switches for use in connection with rotary engines. Two gun triggers are situated in the heart of the grip so as to ease the control and manipulation of the gunfire when in combat by the use of the thumbs instead of the hand. This permits retaining control of the ship with the least effort and allows the pilot to get much better sighting without recurrent handicaps of being obliged to finger around for the trigger control.

WIRELESS GENERATORS.

Wireless generator installations are nearly always effected on military type aircraft in the lower wing, either in the leading edge of wing, on the fuselage side, or fixed on a bracket fastened to the front spar. There was not a single installation on the landing-gear struts in England.

INSTRUMENTS.

The instrument section at Biggin Hill has designed and constructed a sound beam airdrome indicator for use at airdromes in helping pilots to find their landing place in case it is impossible to see the ground because of fog or clouds. This apparatus consists of a big, parabolic, concrete bowl whose concave section is about 15 feet in diameter. This is suspended on a rack about 25 feet above the ground. This bowl can be operated manually at will to face in any direction within a hemisphere. Immediately to one side of this installation is a manually-operated air compressor with storage tank with hand-operated release. This blows a siren whistle which is directed into the bowl. The sound entering this bowl is echoed in a straight line.

The pilot of the incoming airplane, desiring to locate this airdrome in a fog, endeavors to travel along this beam of sound where the intensity is the greatest. Inasmuch as this sound beam is intensified in one direction only, at the control of the operator on the ground, and if the intensity of this sound beam becomes less audible to the pilot of the airplane he immediately tries to get into the zone of high intensification of sound and thereby tries to effect his course in this manner. This is purely experimental and it is not known whether or not it will be entirely practical. However, these experiments should be closely observed and may introduce some possibilities of solution of this difficult problem.

Considerable work is being done in developing navigation instruments. The necessity for this has been manifested in a large measure by the experience gained in the continental commercial air services.

The gyro installations to run the turn indicator are operated by energy from the propeller slipstream on the latest type in England.

LIGHTHOUSES.

The English have developed lighthouses at their Croydon airdrome which have a concrete conical base terminating in a centralized pillar, at the top of which are four electric lights with overhead reflectors which reflect the light against the projected face of the conical base. This is a very easy landmark light to be observed at night, without any hazardous glare.

AERIAL AIRCRAFT CARRIERS.

Experiments have been carried out by the English at the Isle of Grain with a view to determining the practicability of hooking on a cable suspended on each side of a battleship or from an airship. These tests were made by the Royal Air Force pilots with a Sopwith Snipe. A three-eighths-inch cable was suspended in this experiment between four poles (two at either end) situated 200 feet apart. The two poles at either extremity were far enough apart so that a machine could very readily pass between them and engage the main three-eighths-inch cable on flying directly underneath. This is fastened to the two V wires, which in turn are fastened to the two poles at either end of the course. On the main cable a wire loop, approximately 18 inches in diameter, was loosely fastened. About 18 inches above the top plane of the airplane a hook about 10 or 12 inches in diameter was fastened, clearing the periphery of the propeller zone by about 18 inches. This main cable was situated about 25 feet above the ground.

From the success achieved in this experiment it is obvious that the possibility of hooking on the bottom of a dirigible is absolutely plausible. The main precaution to be taken is in keeping the plane upper wing hook at a reasonable distance above the propeller so as not to hit the cable with the propeller. It would be highly advisable to have some pilots volunteer to make experiments in this country with one of our analogous types.

THE ALULA WING.

The Alula wing, designed by Alex Holle, has been developed by the Commercial Wing Syndicate of London, England. This wing has a varying section tapered out

to a point at the extremities of the wing tips. The air foil is twisted from the root out toward the tip in order to decrease the angle of incidence. According to the designer, it will be possible to entirely obviate the end losses prevalent in all present types of wings. The Alula wing is not a specific air foil but a theory which the designer states can not be proven in the wind tunnel but which will give a very high lift wing for weight carriers if tried on a full-scale model.

The Royal Aircraft Establishment conducted wind tunnel tests and then had a wing built and fitted to a Martinsyde F-4 fuselage. They claim that there was no marked advantage or improvement over other types. This was also the conclusion of the French and Italian technical sections and of Doctor Junkers.

There is no actual physical evidence in Europe to prove the superiority of the Alula wing.

AIR MINISTRY TORPEDO MACHINE SPECIFICATIONS.

D. of R. Type 8.

SPECIFICATION OF PARTICULAR REQUIREMENTS TO ACCOMPANY THE GENERAL SPECIFICATION FOR EXPERIMENTAL CONTRACTS.

This specification is to be regarded for contract purposes as being part of the general specification herewith, and as subject to the same conditions.

1. *General requirements.*—The aircraft is to fulfill the duties of "Torpedo-carrying aeroplane for fleet use."

The aircraft is to be designed to accommodate the full equipment specified in paragraph 6.

The aircraft should have a good degree of positive stability in all directions, and trimming gear should be fitted so that the tail plane can be set to insure that the aircraft will fly horizontally at any speed within the flying range without requiring attention from the pilot.

The aircraft must be controllable at all flying speeds and good controllability near stalling speed is essential.

Special attention should be paid to maneuverability.

The aircraft must answer all controls quickly and must not be tiring to fly.

The crew and armament are to be arranged as specified in paragraph 7 of this specification.

The arrangements for alighting and taking off are to satisfy the special requirements laid down in paragraph 8.

The aircraft is to be constructed in conformity with the published requirements of the director of research.

2. *Power unit.*—The engine is to be a Napier Lion (of which the following particulars may be assumed). The engines will be substantially as outlined on the attached installation print.

(*a*) Weight, dry: 840 pounds.
(*b*) Normal horsepower, 2,000 revolutions per minute: 450.
(*c*) Maximum horsepower at 2,100 revolutions per minute: 468.

The propellers are to be so designed that the revolutions per minute stated in (*c*) can not be exceeded under normal circumstances. The engines are to be installed in conformity with the published requirements of the director of research.

A plate is to be affixed in clear view of the pilot, stating that engine is not to be run at the maximum revolutions per minute stated in (*c*) for a period exceeding five minutes.

Tankage, including service gravity tank, is to be provided for—

Fuel, 80 gallons.
Oil, 6 gallons.
Water, 2 gallons.

Gravity tank with a capacity of not less than 16 gallons is to be provided.

Gasoline feed may be either:

(*a*) By Vickers or other approved gasoline pump from the main tanks direct to the carburetors with a by-pass to a gravity tank so situated that in normal flying position there is a minimum effective gasoline head of 20 inches above the gasoline inlets to the carburetors.

(*b*) By Vickers or other approved gasoline pump from the main tanks to a gravity tank, and thence to the carburetors. In this case the gravity tank must be so situated that when the machine is flying at its maximum climbing angle there is a minimum effective gasoline head of at least 20 inches above the gasoline inlets of the carburetors.

The area of the main gasoline pipes should be such that the flow of gasoline sufficient for maintaining full power is exceeded by 100 per cent when the carburetor unions are uncoupled and the supply is in the condition of minimum head.

The cooling and gasoline systems are to be in accordance with the published requirements of the director of research.

Provision is to be made for rapidly emptying the main petrol tanks.

3. *Load to be carried.*—The load to be carried on the acceptance flight is to be as follows:

Crew (1): 180 pounds.
Torpedo Mk. VIII: 1,500 pounds.
Torpedo dropping and adjusting gear: 75 pounds.
Wireless telephony set: 70 pounds.
Torpedo heating gear: 40 pounds.
Aldis lamp: 5 pounds.
Instruments: 40 pounds.
Accessories: 200 pounds.
Fuel, 80 gallons: 584 pounds.
Oil, 6 gallons: 60 pounds.
Water, 2 gallons: 20 pounds.

4. *Contract performance.*—The performance with full load as specified in paragraph 3 and with engine revolutions not exceeding those stated in paragraph 2 (*b*) is to be:

Speed at 2,000 feet, not less than 95 knots.
Rate of climb at sea level not less than 750 feet per minute.
Service ceiling, not less than 15,000 feet.

Length of run required to get off not more than 150 feet in a relative wind of 20 knots, or to the satisfaction of the director of research.

5. *Structural strength.*—The strength of the main structure is not to be less than the following standards when carrying a full contract load as specified in paragraph 3.

Load factor on front truss with center of pressure forward, not less than 6.
Load factor on rear truss with center of pressure back, not less than 4½.

The failing strength of the fuselage is to be determined by the method described in the Handbook of Strength

Calculations HB. 806. The factor required in the limiting nose-dive case is not less than 1.5.

The load factor mentioned above will be determined by the method in the Handbook of Strength Calculations HB. 806.

6. *Equipment.*—The following equipment is to be provided for, and the contractor will be required to supply and fit all parts necessary for its installation.

(*a*) Mark VIII torpedo:

Length, 16 feet 7.4 inches.

Diameter, 18 inches.

Center of gravity, 112.9 inches from aft end.

Provision to be made for carrying alternatively either the Mark VIII or Mark IX torpedo.

(*b*) Torpedo dropping and torpedo depth adjusting gear.

(*c*) Torpedo heating gear.

(*d*) Aldis lamp.

(*e*) Bomb sight.

(*f*) Bomb gear for two smoke-producing float bombs or two 520-pound high-explosive bombs. Weight of smoke bomb, provisionally 300 pounds.

(*g*) Wireless apparatus as specified.

(*h*) Navigation and recognition lighting equipment.

The following instruments of approved pattern are to be fitted in pilot's cockpit.

Air-speed indicator.
Altimeter.
Watch.
Revolution indicator.
Oil-pressure gauge.
Fuel-flow indicator.
Cross level.
Fuel-level indicator.
Radiator thermometer.
Compass.
Torpedo-depth indicator.
Pyrene fire extinguisher.

7. *Disposition of crew and armament.*—The pilot must have a good view downward and forward for the purposes of deck landing. He must also have a good view forward from the horizon downward for the purposes of torpedo sighting. Torpedo-dropping gears and torpedo depth-adjusting gears must be led to the pilot's cockpit.

The alternative bomb load is to be carried under the wings.

8. *Arrangements for alighting and getting off.*—The aircraft is to be designed to take off from the deck of an airplane-carrying ship, with full specified contract load, in the distance specified in paragraph 4 of this specification.

It must be designed to land on the aft deck of such a ship steaming into the wind and a relative wind speed of 20 knots can be assumed.

Provision must be made for the attachment of suitable arresting gear hooks and propeller guard if necessary, and for suitable restraining slings with quick release.

The aircraft must be capable of landing on the water (without torpedo) without turning over and must be fitted with suitable flotation gear, so designed that the machine will remain afloat for six hours in calm weather.

Particulars of the arresting gears as fitted to H. M. ships and of all experiments on flotation gear will be supplied on application to the director of research.

9. *Miscellaneous.*—The aircraft is to be fitted with hoisting slings suitably attached. The slinging gear is to be designed to take three times the "all up" weight of the aircraft.

A pennant is to be run from the hook of the slings to the sternpost, being run along the top longeron, to which it is to be attached by breaking strips. Suitable holding-down rings are to be provided under the bottom planes. The wings are to be designed to fold easily, and with wings folded the maximum over-all dimensions of the aircraft are not to exceed:

Width, 17 feet 6 inches.
Length, 37 feet.
Height, 13 feet.

With wings spread the following dimensions must not be exceeded:

Span, 46 feet.
Length, 37 feet.
Height, 13 feet.
Tall span, 15 feet.

The distance from the leading edge of the forward main plane to tip of rearmost fitting on the aircraft must not exceed 29 feet and 6 inches.

The maximum weight per wheel in pounds should not exceed 12 times the product of the wheel and tire diameters in inches with the aircraft carrying full contract load.

The aircraft is to be designed to resist as far as practicable the corrosive effects of sea water.

10. *Contractor's trials.*—The contractor may be required to demonstrate in the air and with his own pilot that the aircraft is safe to be flown by an officer of the Royal Air force.

11. *Delivery.*—Delivery will be to the officer commanding, Royal Air Station, Martlesham Heath, unless otherwise directed. The first aircraft to be delivered within 12 months of the receipt of instructions to proceed.

12. *Acceptance.*—The aircraft will be accepted on delivery to the above station, but the contractor will be required to make good at his own expense any defects in construction or design which may be revealed while the aircraft is undergoing official trials at the above or any other service station.

13. *Spare parts.*—The following spare parts are to be supplied for each three experimental aircraft:

One complete set of streamline wires.
Three tail skids complete with all fittings.
One complete undercarriage.
One complete tail unit.
Three propellers.

Delivery of spare parts to be made concurrently with the first aircraft delivered, and payment for the aircraft will not be deemed due until this requirement is fulfilled.

THE ROLLS-ROYCE COMPANY.

The Rolls-Royce Co. has practically perfected their Condor 650-horsepower, 12-cylinder, water-cooled, V engine for service use. This engine weighs approximately 2 pounds per horsepower, dry, and its characteristics are as follows.

ROLLS-ROYCE CONDOR AERO ENGINE.

Series 1 A.

General.—The Rolls-Royce Condor aero engine is of the 12-cylinder, water-cooled, V type, fitted with the epicyclic reduction gear, magneto ignition, and complete with propeller hub and engine-supporting brackets suitable for tubular bearers.

The characteristics of the engine are as follows:

- Number of cylinders: 12.
- Bore: 5½ inches.
- Stroke: 7½ inches.
- Normal B. H. P.: 650.
- Normal speed (crankshaft): 1,900 revolutions per minute.
- Maximum speed (crankshaft): 2,000 revolutions per minute.
- Normal speed (propeller) with 0.5537 reduction gear: 1,055 revolutions per minute.
- Fuel consumption at normal power and speed: 45 gallons per hour.
- Oil consumption: 1.9 gallons per hour.
- Weight of engine, including propeller hub, carburetors, magnetos, engine feet, electrical power starter, etc., but excluding reduction gear, exhaust boxes, radiator, oil, fuel, water and starter battery: 1,284 pounds.
- Weight of engine, as above, but including reduction gear: 1,552 pounds.
- Weight of engine, complete with all the above but without radiator, water, oil, fuel, and starter batteries: 1,606 pounds.

Cylinders.—The cylinders are separately mounted on the crank case in two rows of six, at an angle of 60° with each other. They are of built-up all-steel construction, being machined from 0.6 per cent carbon steel forgings with the heads integral with the cylinder barrels. The water jackets are die-pressed sheet steel, acetylene welded at the joints. The valve seatings are machined in the cylinder heads.

Valves.—Two inlet and two exhaust valves are provided per cylinder, operated by overhead cam shafts and rockers. The valves seat direct in the part spherical cylinder heads and their stems are consequently divergent. The valves are made from special high chromium steel forgings, working in phosphor bronze guides.

Cam shaft and rocker mechanism.—The cam shafts are inclosed in steel tubular cases, which are mounted on the top of the cylinders. Each cam shaft is provided with six aluminum bearings which are in halves and bolted together, and two one-piece bearings, one at either end.

To operate the divergent valves, tappets are interposed between the cams and each rocker, the latter being arranged to swing in a plane coincident with or parallel to a plane in which its valve lies.

The cam shafts are machined from 5 per cent casehardening nickel-steel bar, and ground on the bearing surfaces and cam faces. The valve rockers are 3½ per cent nickel-steel forgings machined all over, having hardened ends bearing on the tappets and hardened adjustable end pieces bearing on the valve stems.

Auxiliary gear drives.—The gears for driving the cam shafts and all auxiliaries are driven from the rear end of the crankshaft, through the medium of a spring-controlled friction-damped pinion, so eliminating from all auxiliary drives crank shaft torsional vibrations, and are totally inclosed in a suitable casing. All gears are made from 5 per cent casehardening nickel steel, accurately fitted to shafts running on ball bearings.

Cam-shaft drive.—The cam shafts are driven by means of inclined tubular driving shafts with bevel gear at the upper and lower ends. Out-of-alignment and expansion effects are allowed for by hardened serrated couplings. The driving shafts are supported in ball bearings and the whole totally inclosed in tubular casings.

Pistons.—The pistons are of special aluminum alloy and of the Zephyr type. The advantages of this type of piston are that the crown or head is better supported and the cooling of the piston head is considerably improved.

Five piston rings are provided, arranged as four compression rings above the gudgeon pin and one scraper ring below, at the base of the skirt. The compression rings are prevented from rotation by means of stops.

The gudgeon pins are of 5 per cent casehardening nickel-steel, hardened and ground. A special locking device is used to prevent both axial and rotational movements.

Connecting rods.—The connecting rods are "H" section of the "forked" type, made from 3½ per cent nickel-steel forgings, heat-treated to give a high Brinell, and machined all over to reduce weight variations. A divided white-metal-lined steel bush is gripped by the two caps of the forked rod, the ends of the bush being provided with external grooves which engage corresponding internal grooves formed in the forked rod. The other rod is white-metal-lined and works upon the center portion of the steel bush. The small ends of both rods are fitted with "floating" phosphor bronze bushes. All bearings are positively lubricated under pressure.

Crank shaft.—The six-throw crank shaft is machined from a nickel chrome steel forging, all the journals and crank pins being bored for lightness and to convey lubricating oil to all bearings and connecting rods. All crank pins and journals are accurately ground to close limits for size and trueness of diameter. The crank shaft is carried in seven bearings of ample proportions.

Crank case and bearings.—The crank case is of special aluminum alloy, and is made in two halves of box section suitably ribbed to give the necessary stiffness.

The main bearings consisting of divided phosphor bronze shells, white-metal-lined, are held in the two halves of the crank case, long belts passing through both halves adjacent to each bearing.

A shaft driven from the timing gear is arranged along the inside of the lower half crank case and serves to drive three oil pumps—two scavenger and one pressure—together with the water-circulating pump, these pumps being bolted to the bottom of the lower half.

Reduction gear.—A compound epicyclic reduction gear is fitted on the front end of the crank shaft through which is transmitted the drive to the propeller. The annulus driving gear is fixed on the flange of the crank shaft, which rotates the three sets of planet gears round the sun wheel. The latter is the fixed member of the gear and is prevented from rotating by means of a friction anchorage in the form of a multiplate clutch, the plates being anchored to the casing and the sun wheel alternately, and pressed together

by springs. This arrangement limits the maximum torque which may be imposed on the gears, the clutch being designed to slip if a certain torque is exceeded, due, for instance, to periodic stresses set up by propeller vibrations or preignitions.

The gears and other wearing parts are machined from 5 per cent casehardening nickel steel. The planet gears run on ball or roller bearings and are mounted in nickel-steel planet cages which are bolted to the flange of the propeller shaft. The propeller shaft is made of nickel-chrome steel and supported at its inner end in a bearing mounted in the crank shaft and the front end is carried in a roller bearing of ample proportions.

A double-thrust ball bearing is contained in the front end of the epicyclic gear casing to take thrust from the propeller.

The use of an epicyclic reduction gear as arranged on the Rolls-Royce aero engines prevents any reaction from the driving pressures in the teeth of the reduction gears being transmitted to the crank-shaft bearings, and an efficiency is obtained which is far greater than can be got with any other type of gear, owing to the fact that the direction of motion is not reversed; also the gear only converts part of the horsepower. Lubrication of all working parts is effected from engine crank shaft, and the whole gear is totally inclosed in a gear casing which is carried from the front end of the crank case.

Propeller hub.—The propeller hub is a 3½ per cent nickel steel forging, provided with internal serrations engaging similar serrations on the propeller shaft. To locate the hub radially and to secure it against any axial movement two opposed tapers are utilized, one consisting of a split conical phosphor-bronze ring on the propeller shaft, and the other of a conical nut on the extremity of the shaft, each engaging conical seats in the hub. The loose flange is fitted on serrations of the hub, the whole being provided with a number of hollow bolts which pass through the propeller.

Carburetor.—Two carburetors are provided, each supplying one side of the engine. They are of a special Rolls-Royce Claudel Robson type, fitted with needle-valve adjustment by which the flow of gasoline from float chamber to jet may be regulated from the pilot's seat to suit varying altitudes. Special compensating passages are provided in the carburetor which maintain under all conditions the same pressure in the float chamber as in the throat, thereby neutralizing eddy current effects. These passages also enable the float chamber cover to be sealed, thus reducing the risk of gasoline leakage. In addition, drainpipes are arranged below each carburetor to drain away from the engine any gasoline which may be spilled.

Induction pipes.—The induction pipes are of large diameter, formed with bends and water-jacketed adjacent to each carburetor. Suitable nozzles are fitted in each of the manifolds for priming purposes.

Magnetos and ignition system.—Two 12-terminal high-tension magnetos are fitted and are supported on the auxiliary gear case from which they are driven by means of serrated couplings. Incorporated in the latter is a device for enabling a fine and positive adjustment of the ignition timing to be effected. Two spark plugs of approved make are fitted to each cylinder.

Water circulating pump and cooling system.—A centrifugal water-circulating pump of ample capacity is fitted below the bottom half crank case, being driven from the auxiliary shaft through skew gears.

All water-pipe connections consist of rubber joints with a special patented type of clip, allowing of ample flexibility.

Oil pumps and lubricating system.—The lubrication of the engine is on the "dry sump" system, the bulk of the oil being carried in a service tank separate from the engine. Two scavenger pumps and one pressure pump are arranged on the bottom of the lower half crank case, being driven from the auxiliary shaft. The scavenger pumps draw oil from the crank case and deliver it to the service tank and the pressure pump takes its supply from the service tank and delivers it to the main bearings and other parts under suitable pressure.

A compound relief valve regulates the pressure in the main system and also adjusts the pressure of an auxiliary low-pressure system which supplies oil to the hollow cam shafts, their bearings, and drive mechanism.

Control mechanism.—The control mechanisms for ignition, throttle, and mixture regulator are fitted on the engine, but connections between the engine and pilot's seat are not provided by Rolls-Royce (Ltd.), being left to those responsible for the installation of the engine.

Revolution counter and air pump.—An arrangement for driving a revolution counter is mounted on the timing-gear case, the connection being driven at one-quarter crank shaft speed. An air pump for supplying pressure to the fuel tank can be supplied as an extra, being also mounted on the timing-gear case and driven from the timing gear.

Exhaust manifold.—These are fitted one on each side of the engine, being constructed of light sheet-steel pressings, acetylene-welded together. Suitable union attachments are fitted for connecting the manifolds to light steel exhaust pipes.

Engine-starting gear.—An epicyclic starting gear is fitted on the timing-gear case to which is connected a starting handle on one side and on electric motor on the other.

Priming of the induction pipes is effected by the Rolls-Royce priming device, supplied with each engine, which enables a highly atomized mixture of gasoline and air to be injected into the induction pipes. This device is intended to be fitted near the pilot's seat, and connected to the induction pipes by a copper tube, a length of which is supplied for the purpose.

Direction of rotation.—The direction of rotation of the propeller is clockwise as viewed from the propeller end of the engine.

The engine can be used as either a tractor or pusher.

Spanners, tools, and spares.—A complete set of spanners suitable for carrying out any adjustments to the engine, together with a quantity of spare parts, are supplied in tool box with each engine. A set of special spanners and tools such as are required for dismantling and erection are supplied at an extra cost.

Materials.—All materials used in the construction of these engines are produced in exact conformity with Rolls-Royce specifications, which are based on many years' experience with alloy steels and nonferrous alloys. These

specifications embody all the requirements of the standard specifications issued by the British Air Ministry, but are much narrower in their scope and demand greater freedom from impurities, also closely limit variations of heat treatment.

Testing of materials.—All mild and alloy steels are carefully tested in the raw state, every bar and billet being proved by heat-treatment, fracture, and Brinell test, to insure that the raw material is correct to specificiation.

Each individual crank-shaft and propeller-shaft forging is tested separately. Camshafts, connecting rods, etc., are tested in batches, one forging being selected out of each batch of a specified number and after heat treatment are required to pass the following tests:

(*a*) Tensile (static).
(*b*) Stanton (fatigue).
(*c*) Izod single impact (heat-treatment test).

In the case of nonferrous metals, tensile test pieces are taken from every large casting and from every main cast.

Testing of engines.—All engines are tested in accordance with schedule of standard production and type tests as laid down for aircraft engines by the Air Ministry, and are carried out under the supervision of a representative of the Aircraft Inspection Department.

These engines are of a type and design which have been approved by the Air Ministry, who issue air-worthy certificates after the engines have successfully completed the tests referred to.

ROLLS-ROYCE (LTD.).

FEBRUARY, 1922.

Rolls-Royce patents under which the Condor engine is manufactured.

Description.	British patent number and date.	Foreign patents and dates.
Friction damped spring device.	15333/12 July 1, 1912	French, 459514. June 19, 1913. U. S. A., 1088241. June 24, 1913. Canadian, 154188. June 20, 1913.
Pipe clips.............	104484 Nov. 29, 1916	U. S. A., 1277398. Nov. 20, 1917.
Compensating passages in R. R. C-H. carburetors.	126722	U. S. A. Application No. 217905. Feb. 18, 1918.
Friction anchorage of sun wheel.	129381 Nov. 12, 1917	
Arrangement of three or more radial valves in part spherical cylinder head.	130698 Mar. 18, 1918	French 496491. Mar. 5, 1919. U. S. A. Application No. 295327. Mar. 26, 1919. Canadian, 195352. March 20, 1912. Italy, 174851/83. Mar. 31, 1919.
Copper- titanium-zinc aluminum alloy.	153514 Feb. 25, 1920	French Application No. 140163. Feb. 16, 1921.
		U. S. A. Application No. 446115. Feb. 18, 1921, and others pending.
Copper-titanium aluminum alloy.	153823 Feb. 25, 1920	
Antimony-magnesium-titanium-aluminum alloy.	162467 Feb. 25, 1920	

THE DE HAVILAND COMPANY.

Captain De Haviland has designed several new machines since the war. The most prominent machines that have been constructed are described below.

THE DE HAVILAND 14, DAY BOMBER.

The De Haviland 14, day bomber, is powered with a 650-horsepower Rolls-Royce Condor engine.

The main characteristics of this machine are as follows:

Weight, empty: 4,484 pounds.
Gas, 178 gallons: 1, 280 pounds.
Oil: 160 pounds.
Crew: 360 pounds.
Military load: 1,380 pounds.
Total weight: 7,664 pounds.
Speed at 10,000 feet: 122 miles per hour.
Rate of climb to 10,000 feet: 400 feet per minute.
Length, over all: 34 feet.
Span: 50 feet 5 inches.
Area of wings: 618 square feet.
Gap: 6 feet 5 inches.
Chord: 6 feet 6 inches.

This machine was designed by Captain De Haviland for long-distance day bombing and was gotten out immediately after the war.

The engine is mounted on tubular bearers, which are in turn supported on ply-wood bulkheads, and are very similar to the previous De Haviland types. A large nose radiator is fitted and is completely shuttered.

The oil tank is mounted back of the engine. The gasoline tank is situated right in between the wings immediately back of the engine and in front of the pilot.

Inasmuch as the fuselage is so deep, the gravity tank is formed in the upper part of the main tank, and an ample head of gasoline to the carburetor is assured. Gasoline is fed directly by two independent windmill pumps projected above the fuselage. These can be used in combination, singly, or gravity alone.

The gunner and the pilot are situated immediately back of the trailing edge of the planes and in close proximity to one another. The pilot's armament consists of a Vickers gun mounted on the decking. The gunner's cockpit is provided with a scarf mount and his field of fire is improved to the rear by doing away with the top tail bracing. The tail bracing is accomplished by underslung steel tubes to the bottom of the fuselage.

The instrument board is provided with the Smith gasoline-gauge, which is in the form of a U tube connected with a graduated dial on the instrument board. When it is desired to ascertain the amount of gasoline in the tank, a few strokes on a small hand pump brings the pointer to zero. If the pointer is watched, it will be seen to creep steadily up to a figure which indicates the amount of fuel left. For about 30 seconds the pointer continues upward. For the next reading the pump is again called into service.

In addition to the defensive armament referred to, the De Haviland 14 carries a nest of six 112-pound bombs, carried in two double and two single crates inside of the fuselage ahead of the pilot's cockpit. The fuselage floor is open at the points underneath the crates. To prevent the draft, the openings are covered with sheets of brown paper

which are easily torn by the weight of the bomb. The bombs are normally under the control of the bomber, who releases them by means of a series of toggles on the starboard side of his cockpit. Provision has been made, however, for enabling the pilot to discharge the bombs should necessity arise, by a similar set of toggles in his cockpit.

In this machine the lower longerons are divided into relatively short lengths, the ends of these lengths abutting upon an aluminum block which serves as a base for the ends of two lengths of longerons, one vertical strut, one chassis strut, one cross tube, and divers wiring plates. This is to obviate the danger of crushing the wood at these vital compression points, as has ordinarily been found the case at different times on conventional jobs. The undercarriage is similar to the original De Haviland 4 type. The guard has been placed right back of the main tail skid, of sheet metal, and extends to an extension of the sternpost down to a point underneath the tail trimming king-post. It also serves as an auxiliary tail skid and would prevent danger to the trimming gear in case the tail skid was broken.

The tail planes and wings are of the conventional De Haviland design.

Quantities of these machines have not been built to date.

DE HAVILAND 29 MONOPLANE.

Characteristics:

- Structural weight: 2,687 pounds.
- Weight of wings: 1,110 pounds.
- Weight of machine, empty, with water: 4,200 pounds.
- Weight of machine, fully loaded: 6,600 pounds.
- Area of wings: 440 square feet.
- Area of rudder: 15½ square feet.
- Area of tail plane: 53 square feet.
- Area of elevators: 32 square feet.
- Area of fin: 6½ square feet.
- Total length: 43 feet.
- Span: 54 feet.
- Chord at root: 12 feet 3 inches.
- Chord at tip: 6 feet.
- Tread: 8 feet 9 inches.
- Motor, Napier Lion: 450 horsepower.

The fuselage is constructed of spruce longerons and struts and is covered with three-ply veneer. The fuselage is considerably wider at the bottom than at the top. The main plane is an internally braced monoplane. The wings extend out from the top of the fuselage.

This machine has seating accommodation for 10 passengers inside the cabin. Seats are arranged in two rows along the sides of the cabin, leaving a passageway between the rows. Emergency doors have been provided in the roof to insure the passengers' exit in case of alighting in the water.

The engine mounting is of the detachable unit type. The oil tank is carried under the engine and cooling is taken care of by an engine underslung radiator, as has been used in the DH-18 types. Petro flex gasoline tubes are used throughout the gasoline system. Two gasoline tanks are placed in the leading edge of the wings, one on either side of the fuselage. As ordinarily designed the engine was low enough to allow gravity feed direct to carburetor, but with the new nose it was necessary to install a low-pressure gas system owing to the raising of the engine.

The wings are very heavy and weigh approximately 2½ pounds per square foot. The wing spars are built up of spruce flanges with ply-wood sides, forming a box-spar construction. The flanges themselves are laminated, and consist of three strips of vertical surfaces glued together. These spars are also tapered from root to tip. The ribs are all different in construction and section, on account of the tapering in plan and elevation. The wings are entirely covered with fabric in the ordinary way. The ailerons are of the ordinary type and are slightly twisted after the fashion of most German types of ailerons, near the extremities. No balancing has been provided, although the differential system of aileron control has been provided; that is, the aileron on the low side is not pulled down to such an extent as the high side aileron, thus giving the advantage of greater aileron reaction on the high ailreon side.

All controls work in ball bearings. Cables do not run direct to the elevator king-post but terminate on the cranks of a transverse shaft some distance ahead of the tail plane. From these cranks steel tubes run to the elevators as in the Italian Savoia type. Hinged joints are surrounded with leather protectors and are well greased, practically the same principle as on motor car controls.

The undercarriage is practically of the famous DH-18 type with an Oleo rubber shock absorber unit in the rear leg of the lateral landing gear vees.

As heretofore mentioned, considerable trouble has been experienced with tail controls at low speed, and the machine is very heavy. However, Mr. De Haviland is pursuing the tests of this machine with a view toward developing it and remedying the tail controls in the near future.

The tests on the De Haviland 29 monoplanes are now being carried out, but not much success is being attributed to this type at present.

The first one has crashed, and the main trouble experienced to date has been with proper fore and aft controllability. However, it is hoped by Captain De Haviland to remedy this fault in the near future.

THE DE HAVILAND 34.

The De Haviland Co. has recently gotten out a new type 34 commercial biplane, powered with a 450-horsepower Napier Lion engine.

The main characteristics of this machine are as follows:

- Length, over all: 39 feet.
- Span: 51 feet.
- Height: 12 feet.
- Wing area: 590 square feet.
- Weight of machine, empty, with water: 3,365 pounds.
- Pilot: 180 pounds.
- Useful load—10 passengers with luggage or about 2,000 pounds freight: 2,000 pounds.
- Gas, 80 gallons: 575 pounds.
- Oil, 7.8 gallons: 78 pounds.
- Wireless and electric lighting apparatus: 120 pounds.
- Total weight, loaded: 6,318 pounds.
- Wing loading: 10.5 pounds per square foot.
- Loading per horsepower: 13.8 pounds.
- Cruising speed: 105 miles per hour.
- Duration, at cruising speed: 3½ hours.

This machine follows very closely the general arrangement of the famous De Haviland 18. Its performance is better than the 18 and it has a greater useful load.

The fuselage construction is entirely covered with three-ply veneer and the main passengers' cabin is about 12 feet long, 4 feet wide, and about 6½ feet high. Eight seats are arranged in the main cabin, the ninth being placed opposite the lavatory, and, if desired, the seat next the pilot can be occupied by a passenger, bringing the total capacity up to 10.

The engine installation is similar to the De Haviland 18, of the cantilever type. Its entire mounting is slung by four bolt connections. An underslung radiator is fitted, which can be removed without disturbing the engine or propeller.

Gasoline tanks are situated out, away from the fuselage, underneath the top plane: two independent pressure systems joined to a common junction box and filter.

The wings, tail, undercarriage, etc., are very similar to the 18. The main feature on this machine is the differential aileron movement, first experimented with in the type 29, cantilever monoplane. The idea of the differential control is to get greater angular travel on the high wing aileron or on the wing side that is necessary to exert negative reaction. Ball-bearing controls are fitted throughout. All cables that ordinarily pass through pulleys are attached to sliding, round rods, which slide in strong bearings. These rods are about 18 inches long and thus do away with the chance for wear and tear on the cables that has been so ordinarily prevalent and which has been found to be very dangerous. All the controls are visible and extend on the outside.

The undercarriage is the same as on the 18, with a long shock absorber of about a foot in length in the rear leg of the landing gear V, with an Oleo gear. The whole landing gear can be removed from the machine by merely undoing four bolts.

GLOUCESTERSHIRE AIRCRAFT COMPANY.

MARS 1—HIGH-SPEED RACING TYPE.

Particulars:
- Engine, Napier Lion: 450 horsepower.
- Chord, top plane: 4 feet 9 inches.
- Chord, bottom plane: 4 feet 9 inches.
- Gap: 4 feet 9 inches.
- Stagger: 13½ inches.
- Incidence: 1½°.
- Dihedral: 174°.

Areas:
- Wings: 205 square feet.
- Span: 23 feet.
- Flap, bottom wing only: 18 square feet.
- Top fin: 3.5 square feet.
- Bottom fin: 1.7 square feet.
- Rudder: 5.3 square feet.
- Tail: 28 square feet.
- Elevators: 10 square feet.
- Total weight: 2,500 pounds.
- Loading: 12.2 pounds per square foot.
- Loading per horsepower: 5.5 pounds.
- Petrol: 50 gallons.
- Oil: 6 gallons.
- Water: 8½ gallons.

This machine has since had its radiator changed over to the Lamblin type, similar to the one used for the 300-horsepower Renault motor, and gave 17 kilometers per hour more speed. This shows the advantage of substituting Lamblin (2), free-air type radiators instead of the conventional free-air honeycomb-core type that was originally installed on this machine.

The gasoline tank is placed centrally and stream lined directly over fuselage on the upper wing. The fuselage and wings of the machine look very much like a modified Nighthawk, except that it has a single interior plane strut. Pilot James claimed this machine had obtained a speed of 212 miles per hour over a course.

AIRPLANE "MARS" LV SCOUT, WITH 230-HORSEPOWER B. R. 2 ROTARY ENGINE.

Ailerons.—Top and bottom, 9.3 square feet each. Total area, 28 square feet—65 per cent fixed, 35 per cent movable.

Fins.—1 top and 1 bottom; total area, 5¼ square feet.

Rudder.—Balanced type, area, 5½ square feet.

Landing gear.—V type, built of wood with quick release wheels, 700 millimeters by 100 millimeters, and the usual rubber shock absorbers. A hydrovane is fitted in front for landing on water.

Guns.—Arrangement is made to take two Vickers guns lying along the top of fuselage, and firing through the propeller, by means of mechanical or the Constantinesco gear. One thousand two hundred rounds of ammunition are allowed for.

Flying controls.—Single-control stick for operating lateral control and elevators, foot bar for rudder and lever for adjusting tail. Control wires inside the body are arranged to give straight lead to wires.

Total weight.—Total weight of the airplane is 2,210 pounds.

Military load.—Military load is 401 pounds.

Load factors.—Wings: Factor of 7 on front truss and 5 on rear, working stress of 5,000 pounds per square inch for spruce members. Tail: Factor of 1½; load of 30 pounds per square foot. Body: Factor of 5 for front portion and rear portion with landing loads; rear portion also to have a factor of 1½, with 30 pounds per square foot down load on tail. Landing gear and skid: Factor of 4½; provision is made to fit rack to carry four 20-pound bombs.

$$\text{Load per square foot } \frac{2{,}210}{270}=8.2 \text{ pounds.}$$

$$\text{Load per horsepower } \frac{2{,}210}{230}=9.6 \text{ pounds.}$$

The stability of the machine is extremely good and can be flown with hands off the controls. All controls are very positive in action.

MARS III—DUAL CONTROL TWO-SEATER, TRAINING MACHINE.

General design.—A two-seater machine for training purposes, having good stability in all directions and all controls very positive in action.

Performance.—Maximum speed, 125 miles per hour; landing speed, 55 miles per hour; climb to 10,000 feet, 13 minutes; ceiling, 19,000 feet; flight duration, 2 hours.

Engine.—Bentley rotary, 1,300 revolutions per minute, 230 horsepower. The same engine that was used successfully during the World War.

Gasoline tanks.—Two 16½-gallon main tanks, one at each side of the body, near the center of gravity of the machine; one gravity service tank (7 gallons) located between spars in top center section of wings. All tanks made of tinned steel. The carburetor is fed by gravity from the service tank, which obtains its supply from main tanks by means of a Vickers air-driven gasoline pump. Total gasoline capacity, 40 gallons.

Oil tank.—Situated on top of fuselage near engine. Capacity, 8 gallons.

Fuselage.—Wooden structure braced with tie-rods and fork ends, very rigid structure, stream lined off with fabric.

Wings.—Total surface, 270 square feet; spares (top and bottom), 27 feet 11 inches; chord (top and bottom), 5 feet 3 inches; gap, 4 feet 6 inches; angle of incidence, 3°; dihedral angle, 172°.

Ailerons.—Top and bottom, 9.3 square feet each.

Tail plane.—Total area, 28 square feet—65 per cent fixed, 35 per cent movable.

Fins.—One top and one bottom; total area, 5½ square feet.

Rudder.—Balanced type, 5½ square feet.

Flying controls.—Single-control stick for operating lateral control and elevators, foot bar for rudder, lever for adjusting tail plane. All controls are in duplicate.

Load factors.—Wings: Factor of 7 on front truss and 5 on rear, working to stress of 4,000 pounds per square inch for spruce members. Tail: Factor of 1½; load of 30 pounds per square foot. Body: Factor of 5 on front portion and rear portion for landing loads; rear portion also to have a factor of 1½ with 30 pounds per square foot down load on tail. Landing gear: Factor of 4½.

Total weight.—Total weight of aeroplane, fully loaded, is 2,130 pounds. Pilot and passenger, 360 pounds.

Wing loading per square foot $\frac{2130}{270}$=7.9 pounds.

Load per horsepower $\frac{2130}{230}$=9.3 pounds.

MARS 11 SCOUT, SINGLE-SEATER, "HAWK."

General design.—Fast single-seater scout of high performance, extremely sensitive to control and having the best possible facilities for view in all directions, also capable of getting off a gun turret and alighting on the deck of an aircraft carrier.

Performance.—Speed at 1,000 feet, 127 miles per hour; speed at 10,000 feet, 121 miles per hour; speed at 15,000 feet, 113 miles per hour; climb to 15,000 feet, 19 minutes; ceiling, 19,000 feet.

Engine.—Bentley rotary, 230 horsepower.

Gasoline tanks.—Two 16½-gallon main tanks, one at each side of the body at the center of gravity of machine; one gravity service tank (7 gallons) located between spars in top center section of wings. All gasoline tanks are made of tinned steel. The carburetor is fed by gravity from the service tank, which obtains its supply from the main tanks by means of the Vickers propeller-driven gasoline pump. Gasoline capacity, 40 gallons.

Oil tank.—Situated on top of the fuselage near the engine. Capacity, 8 gallons.

Fuselage.—Wooden structure braced with tie-rods and fork ends, very rigid structure, streamlined off with fabric.

Wings.—Total surface, 270 square feet; span (top and bottom), 27 feet 11 inches; chord (top and bottom), 5 feet 3 inches; gap (at right angles to chord), 4 feet 6 inches; wing section, R. A. F., 15; angle of incidence, 3°; dihedral angle, 172°.

Ailerons.—Top and bottom, each, 9.3 square feet.

Tail plane.—Total area, 28 square feet—65 per cent fixed, 35 per cent movable.

Fins.—One top and one bottom. Total area, 5¼ square feet.

Rudder.—Balanced type; area, 5½ square feet.

Landing gear.—V type, built of wood, with 700 millimeter by 100 millimeter wheels and the usual rubber shock absorbers.

Guns.—Arrangement is made to take two Vickers guns lying along the top of fuselage, and firing through the propeller, by means of mechanical or the Constantinesco gear. One thousand two hundred rounds of ammunition allowed for.

Flying controls.—Single-control stick for operating lateral control and elevators, foot bar for rudder and lever for adjusting tail, control wires inside body arranged to give straight lead to wires.

Total weight.—Total weight of airplane is 2,180 pounds.

Military load.—Military load is 401 pounds.

Load factors.—Wing: Factor of 7 on front truss and 5 on rear, working stress of 4,000 pounds per square inch for spruce members. Tail: Factor of 1½; load of 30 pounds per square foot. Body: Factor of 5 for front portion and rear portion with landing loads, rear portion also to have a factor of 1½ with 30 pounds per square foot down load on tail. Landing gear and skid, factor of 4½. Provision is made to fit rack to carry four 20-pound bombs.

Load per square foot $\frac{2180}{270}$=8.0 pounds.

Load per horsepower $\frac{2180}{230}$=9.5 pounds.

The stability of the machine is extremely good and can be flown with hands off the controls. All controls are very positive in action.

COMMENTS.

All of the Gloucestershire aircraft designed by Mr. Folland are geometrically similar and have the same identical characteristics of construction and as many interchangeable parts as consistent in practice. These machines are all very similar to the Nieuport Nighthawk, Nieuport Goshawk, and Ses-5 series of airplanes. Mr. Folland was largely instrumental in the design of all these ships.

HANDLEY PAGE.

The most interesting thing about the Handley Page Co. is still their slotted wing. The company is still building large machines, and a good description of one of their latest models for commercial work is given below.

HANDLEY PAGE WING.

Mr. Handley Page's slotted air foil has been installed on a De Haviland 9 and also on a monoplane, using a DH-9 fuselage, landing gear, and empennage. The theory of the slotted wing is not yet susceptible of complete mathematical treatment, but the effect can be dealt with in qualitative fashion.

The lift on any plane is due to combined effect of a suction on the upper surface and a pressure underneath. While pressure on the underneath side increases continually with increasing angle, the suction on the upper surface reaches a critical angle when between 10° and 15° angle of inclination of the chord line of the plane to the horizontal. After this angle is reached, steady flow of the air is broken and burbling results. To avoid this effect and to obtain a continuous increase of the suction effect on the upper surface of the plane to much larger angles than 15°, the slotted plane was devised.

In its simplest form it consists of a narrow slot extended transversely across the plane in the direction of the span. It has a wide opening on the undersurface connected to a narrow exit in the upper surface of the plane. The exit is controlled by a hinged flap extending all along the leading edge of the air foil section and is controlled manually from the pilot's cockpit.

This operates by introducing a new live air stream to the upper surface of the plane and prevents the burbling state. It also allows a suction effect on the upper surface of the plane to continue to a larger angle than before with a consequent higher maximum lift plane. The performance of this air foil has been to effect landing speed that is much lower with a given wing area than we have been ordinarily obtaining with the conventional air foil.

The slot arrangement is mechanically controlled from the pilot's cockpit by control of a hinged, counter-leading edge, surface of air foil section which controls the width and extent of the slot opening at the will of the pilot.

It is practically impossible to get a good ratio of lift to resistance and high maximum lift with the same section. A good ratio of lift to resistance necessarily means a low value of maximum lift while a high value of the lift coefficient means a low value of the lift to resistance ratio. The Handley Page Co. hoped to realize the combination of both by putting in this variable device which will admit of two different effects of the resulting air flow. It is to effect this combination that the new design, known as the slotted plane, was devised.

The experiments with the De Haviland 9 show an approximate increase of 40 per cent of the lift coefficient with the slot opening. The second machine was a cantilever type plane. When tested out in the wind tunnel this second machine gave a maximum lift coefficient of 0.77 absolute unit unslotted and 1.035 when slotted. The full-size machine was loaded to 11 pounds per square foot, and the machine landed at 43 miles per hour, corresponding to the lift coefficient of 1.17 in absolute units. This high-lift coefficient with the high-lift wings proves, according to Mr. Handley Page, that model results still hold good as with wings of thinner sections. In this machine the opening and closing of the slot was carried out by means of the variation of the auxiliary plane control by a lever beside the pilot. Very equal weight lifted in the same landing speed proves that this new slot device is not heavier than ordinary construction.

Mr. Handley Page is at present working on a torpedo type plane, details of which are not available. This machine is to be equipped with his slotted wing and experiments conducted. On the whole, this wing represents marked departure in high-lift sections and should be experimented with on full-scale models to ascertain the ultimate benefits to be derived from this type.

THE HANDLEY PAGE W 8 B.

The Handley Page W 8 B, equipped with two Rolls-Royce Eagle engines is an interesting commercial development.

The main characteristics of this machine are as follows:

Weight, empty, with water: 7,700 pounds.
Pilot: 160 pounds.
Gas for 3¼ hours: 1,000 pounds.
Oil, 10 gallons: 100 pounds.
12 passengers: 2,160 pounds.
Cargo: 880 pounds.
Total weight: 12,000 pounds.

The performance is as follows:

Maximum speed at ground: 104 miles per hour.
Maximum speed at 500 feet: 101 miles per hour.
Rate of climb at ground: 550 feet per minute.
Service ceiling: 10,000 feet.
Landing speed: 54 miles per hour.
Length: 60 feet.
Span: 75 feet.
Chord: 10 feet.
Gap: 11 feet.
Area of wings: 1,456 square feet.

Gasoline tanks are placed on top of the upper plane, with the resulting advantage of a greatly simplified gasoline system. This obviates the necessity for extensive piping and gasoline pump installation with complicated fuel systems. No rubber gasoline connections are employed. Air Ministry type metal couplings are used throughout. Each tank is provided with a gasoline level indicator of the Clift pattern.

The mounting of the engine is not essentially different from the previous Handley Page types.

Instead of a biplane tail, however, as in the Handley Page 0, 400-type, a single stabilizer and single elevator have been installed in conjunction with a fin and counter-balancing rudder. The ailerons employ the Handley Page aileron leading edge counter-balancing feature.

The large cabin will have accommodation for 12 passengers, and there is a smaller cabin of 70 cubic feet capacity for luggage in the rear. A tip-up seat is situated at the side of the pilot so that, if desired, a mechanic can be carried there.

An adjustable tail is provided so that the pilot can adjust the machine for any conditions of load and speed.

The equipment is made up of wireless telegraph apparatus, two air-speed indicators, two altimeters, two inclinometers, two revolution indicators, two radiator thermometers, two oil-pressure gauges, two gasoline-level indicators, two oil thermometers, two Pyrene fire extinguishers.

The pilot and mechanic sit out in the nose of the fuselage proper. Two two-wheel landing gears are situated on either side of the fuselage underneath the engine mounting proper. The shock absorbers are installed in the front legs of these.

This machine will be used for passenger traffic between London and Paris and on other lines to European points.

THE BRISTOL CO.

The Bristol Co., of England, manufacturers of the well-known Bristol Fighter and a long line of less known military aircraft, are still one of the leading aeronautical manufacturing firms in England. Their new Bristol 10-seater commercial airplane and their Bristol Jupiter engine are two aeronautical accomplishments meriting full description.

The characteristics of the Bristol 10-seater are as follows:

General description.—The Bristol 10-seater airplane is a single-engined tractor biplane, having an inclosed cabin for eight passengers and an open cockpit for pilot and mechanic.

Engine installation.—The 400-horsepower Bristol Jupiter engine is mounted on a readily removable swinging mounting, which gives instant access to the back of the engine and dispenses with any necessity for removing cowling.

A steel fireproof bulkhead is fitted behind the engine and all control connections pass through glands. No gasoline is carried in the body aft of the fire bulkhead.

Saloon.—The saloon is entered through a door aft of the lower plane and seats six of the passengers facing forward in separate chairs, the other two facing aft. The seats are collapsible and when folded project only 5 inches from the saloon sides, leaving a maximum of floor space if it is desired to carry cargo in lieu of passengers.

Windows, which can be opened, are fitted the full length of both sides of the cabin and an emergency exit is provided in the roof. Heating is provided by means of hot-air muffs around the exhaust pipes. Behind the saloon is a lavatory compartment suitably fitted.

The internal dimensions of the saloon available as cargo space when no passengers are carried are: Length 10 feet 6 inches; height at center, 5 feet 9 inches; width, 4 feet.

Pilot's cockpit.—The pilot and mechanic are accomodated in a cockpit between the fire bulkhead and the front spar of the top plane, giving a very fine view. A wireless telephone and telegraph installation is provided for in the cockpit (but not supplied), completely accessible to the mechanic.

Luggage hatch.—Below the pilot's cockpit is a luggage compartment, 4 feet 6 inches long by 4 feet wide by 2 feet 6 inches high, accessible through a trapdoor in the underside of the fuselage.

Gasoline system.—The two main gasoline tanks, of 45 gallons capacity each, are slung under the bottom planes at the inner interplane strut. Gasoline is drawn from either of these tanks by two Vickers centrifugal pumps coupled in series, and delivered through a Vickers hand pump to the carbureters, any surplus being returned through a 10-gallon gravity emergency tank, fitted high up on the fire bulkhead. Smith's capacity gauges for both main tanks are fitted on the instrument board.

Chassis.—The chassis is of the two-wheeled Oleoelastic type. Elastic rings are used for suspension and the elastic carriers have been designed for ready renewal of these rings. The Oleo plungers are fitted with a special type of tapered needle valve to control the passage of the oil through the plunger to give constant oil pressure throughout the stroke of 8 inches.

Flying controls.—Single control of the wheel type is fitted, all cable pulleys being 5 inches diameter.

Tail trimming gear.—The tail incidence can be varied by a lever and quadrant adjacent to the pilot to trim the machine under all conditions of speed and load distribution.

Dimensions.—Span, 57 feet, 6 inches; length, over all, 40 feet, 6 inches; height, 11 feet.

Weights.—Machine, empty, 4,000 pounds; fuel—gasoline, 90 gallons, oil, 6 gallons, 715 pounds; crew (2) at 160 pounds, 320 pounds; passengers (8) at 150 pounds, 1,200 pounds; baggage, 350 pounds; wireless, etc., 65 pounds; total, 6,650 pounds.

Loading.—Weight per horsepower (Bristol Jupiter at 400 horsepower), 16.6 pounds; weight per square foot, 9.3 pounds.

Performances.—Speed at ground level, 112 miles per hour; speed at 5,000 feet, 110 miles per hour. Time to climb to 1,000 feet, 1½ minutes; time to climb to 5,000 feet, 13 minutes.

This machine is being used by the Handley Page Co. on their Paris-London air line. So far the machines have been equipped with the Napier Lion engine. However, they propose as they increase the number of these machines on this line to install the new Bristol Jupiter engines. This machine is a very fine passenger-carrying type and embodies practically the latest conception of pilot location, passenger location, engine installation, and disposition of fuel tanks. The fuel tanks are located underneath the bottom wing so as to obviate any danger of fire in case of a crash. The landing gear has a shock absorber in the rear leg of the landing gear V.

THE BRISTOL JUPITER 400-HORSEPOWER 9-CYLINDER AIR-COOLED ENGINE.

The characteristics of this engine are as follows:

- Bristol Jupiter engine, air-cooled radial: 380 horsepower.
- Code name for telegraphic and other purposes: Jupiter.
- Direction of rotation: Left-hand tractor.
- Number of cylinders: 9.
- Bore: 5¾ inches.
- Stroke: 7½ inches.
- Rated full power at normal revolutions per minute: 380 brake horsepower.
- Normal speed: 1,575 revolutions per minute.
- Maximum speed: 1,625 revolutions per minute.
- Weight: 725 pounds.
- Fuel consumption per brake horsepower hour: 0.6 pint.
- Oil consumption per brake horsepower hour: 0.45 pint.

The engine to be constructed in accordance with general arrangement, detail and installation drawings, supervision sheets, schedule of parts, and material specifications, which shall first be submitted to and approved by the director general of supply and research, and to comply with the following general conditions:

(a) Special considerations must be given in the design to enable periodical inspection, adjustment, and top overhauls to be conducted in a minimum of time and with a minimum of labor (i. e., without removal from machine).

(b) The engine must be capable of functioning satisfactorily at all reasonable inclinations of the machine.

One set of tracings and three complete sets of prints of approved general arrangement and detail drawings, schedule of parts and material specifications drawn up in accordance with standard Air Ministry requirements, together with six prints of installation drawings, enumerating all essential details and dimensions affecting installation to be supplied on placing of contract.

Approval of designs and modifications.—All designs and modifications are to be submitted to and approved in writing by the directorate of research.

Materials.—(a) Materials employed in the construction of the engine are to conform to B. E. S. A. standards and the selected schedule approved by the director of research.

(b) Screw threads for studs and bolts employed in the construction of the engine to be in accordance with those laid down in T. D. I. 532.

Tests of power, gasoline, and oil consumption, slow running.—Supervision of tests, etc.—The engines will be designed to conform to and will be submitted to the conditions of the schedule of standard production and type tests for aircraft engines, dated March 30, 1920.

Fire prevention.—(a) Careful provision must be made for draining the carburetor and intake pipe to prevent the accumulation of gasoline.

(b) Carburetors must be disposed in such a manner that the intake can be led outside the aircraft cowling without interfering with the normal functioning of the carburetor.

(c) To avoid danger from fire, in the event of the carburetor flooding, and popping back occurring, the air intake must be carefully fitted with tight joints not likely to break down through vibration.

(d) No soft-soldered joints are to be used in the gasoline piping of the engine.

(e) Rubber gasoline pipes must not be employed in the engine. No rubber flexible connections may be employed on the engine.

(f) In order to insure the requisite margin of safety, to obviate failure with consequent danger from fire, all exhaust, induction, and air intake piping and joints which would be normally inside the machine cowling must be designed to withstand a pressure of 80, 50, and 25 pounds per square inch, respectively.

Ignition system.—(a) Dual ignition shall be provided for with two spark plugs per cylinder.

(b) Two magnetos, B. T. H. type, A. Q. 9, shall be provided and fitted with an approved form of vernier adjustment to the timing on the gear drive. The magnetos shall be of the latest type and embody all approved modifications.

(c) K. L. G. type F. 12 spark plugs shall be provided (2 per cylinder).

(d) The high-tension cables from the magneto distributors to the spark plugs shall be in accordance with Section I of B. E. S. A. Specification No. 3 E. 1. The plug ends of the leads shall be fitted with terminals of approved pattern.

Carburetor, altitude, and ignition controls.—The carburetor, altitude, and ignition controls are to be interconnected and conveniently brought to a countershaft on the engine, with provision at each end of the countershaft for a connection between the engine and pilot's control lever.

Carburetors.—(a) Adequate provision is to be made for heating the mixture to insure effective vaporization of the gasoline.

(b) A minimum of 35 per cent vacuum control must be provided on the gasoline system to compensate for variation at altitude.

(c) Arrangements are to be provided by interlocking the altitude and throttle control to enable the mixture to be brought to the fully rich position when closing the throttle.

(d) The carburetors must be capable of functioning efficiently at the maker's declared maximum B. H. P. output with a gasoline head range from 12 feet to 18 inches, and to give uniform and even acceleration throughout the throttle range.

Lubricating pipes.—All lubricating pipes of three-eighths-inch bore or less are to be weldless steel. No lubricating pipes under one-fourth inch bore are to be employed. If a smaller flow than a pipe of this size will provide is required, the nipple is to be choked to give the correct oil distribution.

Gasoline and oil connections.—(a) All gasoline and oil connections and controls are to be completed on the engine as far as possible, so that the installation of the engine in the machine is rendered as simple as possible.

(b) All pipes are to be electrically grounded to "earth" in the engine in accordance with D. of R. requirements.

Gasoline pump.—A suitable and accessible drive is to be provided to allow for an engine-driven gasoline pump to be fitted. The flange for mounting and spindle for driving the pumps are to be in accordance with the R. A. F. standard, size No. 2.

Starting arrangements.—Provision is to be made for the use of the Royal Aircraft Establishment type of starter. An approved type of nonreturn valve is to be fitted to the cylinder, and suitable drive and distributing valves incorporated on the engine.

Revolution indicator drive connection.—Suitable drive must be provided for direct connection of the standard flexible shaft, running at one-fourth engine speed, for the revolution indicator.

Exposed drives and wearing parts.—All exposed drives and wearing parts are to be protected from the ingress of fine sand and foreign matter incidental to conditions prevailing under certain climatic conditions.

Port openings.—All uncovered port openings are to be provided with suitable coverings to prevent the ingress of foreign matter during transit and storage.

Slinging of engines.—Suitable provision is to be made by permanent fixtures to the engine body for slinging purposes.

Gun-control gear.—Brackets for carrying two C. C. gun gear generators, with cams for their operation, and the necessary engine attachments and fixings to be supplied and fitted.

Propeller hub.—The propeller hub is to be designed in accordance with B. E. S. A. standard requirements, the dimensions enumerated below being standardized to promote interchangeability.

(a) Diameter of flanges.
(b) Distance between flanges.
(c) Diameter of propeller boss shaft.
(d) Number of bolts.
(e) Diameter of bolts.
(f) Pitch of circle of bolts.

This engine has passed the Admiralty 50-hour dynamometer tests and has shown up very well indeed for an air-cooled engine. It is very light. When one considers its weight of 1¾ pounds per horsepower, it can be readily seen what a stride this engine represents in the aeronautical motor work. The diameter over all of this engine is approximately 50 inches. Of course this makes it rather difficult to cowl in a single-seater pursuit plane and makes quite a large nose.

LUCIFER 100-HORSEPOWER ENGINE.

Another type that the Bristol Co. has developed has been the Lucifer 100 horsepower type with three cylinders of the same size as are used in the Jupiter type. Dual ignition is provided in the Lucifer and the total weight of the engine is about 300 pounds. The normal revolutions per minutes are 1,600. This engine has been designed primarily to provide a comparatively low power unit. The main considerations of the Bristol Co. have been reliability in long life combined with low cost of upkeep and ease of production. No attempt has been made to cut the weight, but to obtain the maximum durability and performance from the engine. The parts have been reduced to a minimum and everything sacrificed for endurance and long life. This motor is not a military type.

THE VICKERS CO.

The Vickers Co.'s main project at the present time is building the Vickers Vimy troop transport. It is a twin Napier engined airplane equipped for carrying 16 troops with their personal field equipment. Most of these ships are going to be used in Mesopotamia. The characteristics of this type are analogous to the Vickers Vimy passenger-carrying type. This machine is now being equipped with Oleo type shock-absorbing landing gear instead of the conventional Vickers Vimy rubber shock-absorbing type.

The Vickers machines are all equipped with the famous Vickers centrifugal gasoline pump, and in case of the failure of this feed the pilot has in reserve a hand gas pump, permitting the replenishing of the gravity tank by the hand operation of his pump.

The Vickers troop-carrier control systems are all compensated by telescopic spring arrangements connected to the control in the cockpit. The fuselage of the Vickers troop carrier is entirely of monocoque construction and the wings and tail surfaces are of the conventional Vickers Vimy bomber construction.

VICKERS 8-SEATER PASSENGER.

The Vickers Co. is getting out an experimental 8-seater passenger-carrying airplane equipped with Rolls Royce Eagle engine. This machine has a monocoque fuselage with the pilot situated at the head of the upper wing, as in the Bristol 10-seater type. The characteristics of this machine are as follows:

Wings, high lift: T 64.
Weight of machine, empty: 3,495 pounds.
Pilot: 180 pounds.
Gasoline (72 gallons): 510 pounds.
Oil (5 gallons): 45 pounds.
Reserve water (2 gallons): 20 pounds.
Wireless apparatus: 100 pounds.
Passengers (8 at 160 pounds): 1,280 pounds.
Baggage (8 at 30 pounds): 240 pounds.
Total weight: 5,870 pounds.

General characteristics:
Length, over all: 37 feet 5 inches.
Height, over all: 14 feet 3 inches.
Span: 46 feet.
Chord: 9 feet 3 inches.
Gap at fuselage: 8 feet 2 inches.
Incidence of main planes: 3°.
Dihedral of top plane: 0°.
Dihedral of bottom plane: 3°.
Area of main planes: 785 square feet.
Loading per square foot: 7.5 pounds.
Loading per horsepower (370): 15.85 pounds.

Estimated performance:
Full speed near seal level: 106 miles per hour.
Climb to 6,000 feet: 13.25 minutes.
Full speed at 6,000 feet: 103.5 miles per hour.
Service ceiling: 10,850 feet.
Landing speed: 42 miles per hour.
Duration at 90 miles per hour at 6,000 feet: 360 miles.

The Vickers Co. is also constructing a number of Vickers Viking amphibian flying boats equipped with Napire Lion engines. They are also constructing an experimental model of a bombardment type with twin Napier Lion engines. It has an all-steel fuselage and landing gear and wooden wings. No characteristics of this type could be obtained, as it is one of the new Admiralty types that is confidential.

It has been satisfactorily operated in experiments to determine the practicability of using the Thames. Several flights have been made upon the Thames and the Seine near Paris. Three passengers may be carried in the open cockpit. The maximum speed is approximately 120 miles per hour. The minimum speed is 52 miles per hour and the cruising speed 82 miles per hour.

The Vickers Viking F-4 is an amphibian flying boat with a better commercial performance than the Viking 3, and is fitted with folding wings which fold forward in order to facilitate housing. The toal weight is 5,600 pounds; and allowing for a pilot, fuel and oil, 1,090 pounds is available for a commercial load. The maximum speed is 119 miles per hour and the cruising speed 90 miles per hour.

Four passengers can be carried, two in the forward cockpit, the third in an aft position where the gunner would ordinarily sit, and the fourth beside the pilot. Alternately, the space provided for passengers can be used for goods.

The Vickers Co. has adapted one of their Vickers Vimy machines as an ambulance plane in accordance with Admiralty specifications for this type. This plane is probably the best interpretation of an ambulance type that has been built by any nation to-day. A complete description of the machine is given under the heading, "Air Ministry ambulance plane specifications," which follows this article in the report.

AIR MINISTRY—DIRECTORATE OF RESEARCH—VICKERS VIMY, MODIFIED FOR USE AS AMBULANCE AIRPLANE.

SPECIFICATION OF PARTICULAR REQUIREMENTS TO ACCOMPANY THE CONTRACT AGREEMENT.

This specification is to be regarded for contract purposes as being part of the contract agreement, and as subject to the same conditions.

1. *General requirements.*—The aircraft is to be a Vickers Vimy commercial type, modified so as to fulfill the duties of ambulance airplane, and is to be generally similar to the experimental Vimy ambulance, except as hereinafter stated.

The aircraft is to be designed to carry the full equipment specified in paragraph 6 of this specification.

The aircraft must have a good degree of positive stability in all directions.

The aircraft must be controllable at all flying speeds. The standard Vimy commercial elevator controls must be so modified as to give increased elevator movement.

The passengers' compartment is to be equipped as specified in paragraph 7 of this specification.

The arrangements for landing and taking-off are to be as specified in paragraph 8.

The aircraft is to be constructed in conformity with the drawings approved by the director of research or his representative.

2. *Power unit.*—The engines to be installed are Napier Lions, of which the following particulars are to be assumed:

(*a*) Weight, dry: 912 pounds.
(*b*) Normal horsepower at 2,000 revolutions per minute: 470.
(*c*) Maximum horsepower at 2,100 revolutions per minute: 487.

The propellers are to be designed so that the maximum revolutions stated at (*c*) can not be exceeded under normal circumstances.

The propellers should also be so designed that the engine revolutions at full throttle, when the aircraft is stationary on the ground, are approximately 1,800 revolutions per minute.

The engine installation is to be in accordance with the requirements of the director of research.

The exhaust manifolds are to be fitted with an efficient silencer.

A plate is to be fitted, in clear view of the pilot, stating the normal and maximum permissible revolutions of the engine, with a warning to the effect that the engine is not to be run at the maxim revolutions as stated at (*c*) for a period exceeding five minutes. The throttle control is to be of gate pattern, of which particulars will be supplied. An instruction plate is to be provided, worded as follows: "The throttle lever must not be moved through the gate except when above 5,000 feet, or in case of emergency."

Tankage, including gravity tank, is to be provided for—

Fuel, 167 gallons.
Oil, 14 gallons.
Reserve water, 4 gallons.

The gravity tank must have a capacity of at least 32 gallons.

Petrol system.—The petrol system is to be in accordance with the drawings approved by the director of research.

Rubber as jointing material is to be eliminated as far as possible from the petrol system. All couplings are to be of all-metal type (Air Ministry pattern).

The petrol feed is to be by approved pumps from the main tanks direct to the carburetors, with a by-pass to a gravity tank, so situated that when the aircraft is flying at its maximum climbing angle there is a minimum effective petrol head of at least 20 inches above the jet level at the carburetors.

The delivery from the pumps to the carburetors must be via an approved release valve to a distributor cock or cocks, so arranged that the following selections can be obtained:

(1) Pumps to carburetors and gravity tank.
(2) Pumps to carburetors only.
(3) Gravity tank to carburetors.
(4) Off.

An overflow pipe of sufficient bore to deal with all excess petrol must be provided from the main tank to the gravity tank.

A petrol flow indicator is to be fitted in this overflow pipe, in a position clearly visible to the pilot.

An auxiliary hand petrol pump of approved design is to be fitted between the main and gravity tanks and must be capable of supplying sufficient petrol to maintain full power. The bore of the main petrol pipes must be such that the flow of petrol sufficient for maintaining full power is exceeded by 100 per cent when the carburetor unions are uncoupled, and the supply is in the condition of minimum head.

A Jettison valve is to be fitted into each of the main petrol tanks.

Cooling system.—The cooling system must be in accordance with the drawings approved by the director of research, and provision is to be made for the fitting of auxiliary radiators, of such size as to make the system suitable for operation in tropical climates, as and when necessary.

The aircraft will be delivered with the standard radiators and the necessary suspension fittings for auxiliary radiators. The auxiliary radiators will be delivered in separate cases at the same time as the airplanes.

3. *Load to be carried.*—The load to be carried on acceptance flight is as follows:

	Pounds.
Crew (2)	360
Attendant (1)	180
Patients (9)	1,440
Wireless equipment	150
Water and tanks (medical)	110
Rations	80
Fitted ice chest	100
Stretchers	40
Electrical equipment	160
Service load	2,600
Petrol, 167 gallons	1,200
Oil, 14 gallons	140
Reserve water, 4 gallons	40
Total load	3,980

4. *Contract performance.*—The contract performance with the aircraft loaded to a total weight of 12,500 pounds and with engine revolutions not exceeding those specified in paragraph 2 (*b*), is to be: Speed at 6,500 feet, not less than 98 miles per hour; climb to 6,500 feet, in not more than 16 minutes; service ceiling, not less than 12,000 feet.

5. *Structural strength.*—The strength of the main structure is to be not less than the following standards when the aircraft is loaded to a total weight of 12,500 pounds: Load factor on front truss with center of pressure forward, 4; load factor on rear truss with center of pressure back, 4; factor in terminal nose dive, 1. The above factors, and the failing strength of the fuselage will be determined by the methods described in the Handbook of Strength Calculations HB. 806.

6. *Equipment.*—The following equipment is to be provided for, and the contractor will be required to supply and fit all parts necessary for its installation, including all necessary wiring, such installation to be in accordance with the general instructions issued by the director of research.

Wireless Equipment: C. W. transmitter type 21; receiver model T. f.: earth system Part I; D. F. for ground use.

Equipment schedule (wireless).

Item.	Reference No.	Description.	Quantity.	Supply.	Fitted by—
1	10/4869 L	Arm swiveling, left-hand.	1	R. A. F. on repayment.	Contractor.
2	10/1753...	Brackets aluminum suspension fitted.	4	.....do.........	Do.
3	10/570.....	Clamp aluminum floor, 1 inch.	1	....do..........	Do.
4	10/124....	Reel, aerial type 3..	1	....do..........	
5	10/243....	Roller fitting....... or	1	.....do.........	Do.
5A	2636...	Bush, steel, 1 inch..	1	.....do.........	Do.
6	G. 4957..	Saddles, red fiber, 1 line P 3.	6	.....do.........	Do.
7	G. 6702..	Saddles, red fiber, 2 line P 11.	25	.....do.........	Do.
8	G. 4954..	Saddles, red fiber, 3 line P 11.......	6	.....do.........	Do.
9	G. 320....	Terminal earth.....	1	.....do.........	Do.
10	10/216....	Tube Dexine, 1 inch.	1	.....do.........	Do.
11	G. 1108..	Cable, electric, P 3.. ....yards..	2	.....do.........	Do.
12	5C/21.....	Cable, electric, P 11 ....yards..	25	.....do.........	Do.
13	G. 6706..	Cable, electric, pattern 482...yards..	8	.....do.........	Do.
14	G. 1095..	Cable, electric, P 13 ....yards..	5	.....do.........	Do.
15	10/1786...	Masts, bentwood, telescopic.	1	.....do.........	Do.
16	G. 1004..	Cable eyes, 2 BA...	18	.....do.........	Do.
17	G. 1003..	Cable eyes, 0 BA...	6	.....do.........	Do.
18	10/2880...	Battery inert, 15-volt.	6	R. A. F.........	R. A. F.
19	10/2766...	Box battery, 90-volt.	1	.....do.........	Do.
20	10/4576...	Case valve transit, 3-valve.	1	.....do.........	Do.
21	10/736....	Cells, dry, type "R"	3	.....do.........	Do.
22	10/2789...	Case transit wavemeter, CW No. 3.	1	.....do.........	Do.
23	10/2051...	Control resistance and voltmeter.	1	.....do.........	Do.
24	10/117....	Cord telephone with plug.	1	.....do.........	Do.
25	10/1618...	Generator, H. T. air-driven, 1,500 volts, 150 watts.	1	.....do.........	Do.
26	10/1303...	Key, transmitting C. W.	1	.....do.........	Do.
27	5C/243...	Lamp electric Min. E. S. caps, 2.2 volts.	3	.....do.........	Do.
28	10/1806...	Receiver, model T. F.	1	.....do.........	Do.
29	10/115....	Receiver, telephone with headgear, 750 ohms.	1	.....do.........	Do.
30	10/2921...	Transmitter, type 21.	1	.....do.........	Do.
31	10/1123...	Valves, type "R"..	3	.....do.........	Do.
32	10/1120...	Valves, type "A"..	3	.....do.........	Do.
33	10/2562...	Wavemeter, C. W. No. 3.	1	.....do.........	Do.
34	10/4911..	Weight aerial, C. I. with spring.	1	.....do.........	Do.
35	10/1998..	Windmill, 24-inch pitch.	1	.....do.........	Do.
36	10/4589..	Wire aerial, R. 4 ....feet..	300	.....do.........	Do.

Equipment schedule (wireless)—Continued.

Item.	Reference No.	Description.	Quantity.	Supply.	Fitted by—
37	10/1584...	Generator, hand driven, 1,500-volt.	1	R. A. F......	R. A. F.
38	10/5417...	Accumulator, 6 volts, 37 amp./hr.	1	.....do........	Do.
39	....	Coil, collapsible D. F., complete.	1	.....do.......	Do.

Electrical equipment: Services are to be provided for navigation lights; heated clothing (2); Aldis lamp; R. L. tube; internal lighting; identification equipment; W. T. supply; Holt flares; kettle.

Equipment schedule (electrical).

Item.	Type.	Description.	Quantity.	Supply.	Fitted by—
1	T28153.....	Air screw..........	1	R. A. F...	R. A. F.
2	500 W......	Generator, Mk. III	1	.....do....	Do.
3	No. 3......	Generator cradle..	1	.....do....	Do.
4	....	Generator mounting.	1	Contractor	Contractor.
5	No. 3, Mk. III.	Accumulator......	2	R. A. F...	R. A. F.
6	No. 5, Mk. III.	.....do...........	1	.....do....	Do.
7	No. 2, Mk. III.	Voltage control box.	1	.....do....	Contractor.
8	30.0.30....	Ammeter..........	1	.....do....	Do.
9	Lucas......	Switch box No. 8..	1	.....do....	Do.
10	Rotax.....	Switch box No. 3..	1	.....do....	Do.
11	P.S.H.T..	Navigation lights..	4	.....do....	R. A. F.
12	....	Navigation light mountings.	4	.....do....	Contractor.
13	1 D. F.....	Identification lights.	2	.....do....	Do.
14	1 U. P., old patent....	Identification switch box.	1	.....do....	Do.
15	New patent.	W/T. switch......	1	.....do....	Do.
16	....	Cockpit lights.....	2	.....do....	Do.
17	Holt.......	Night landing flares, sets.	2	.....do....	Do.
18	....	Multi plug and socket.	4	.....do....	Do.
19	{ 8 amp... { 20 amp...	Plug and socket, 2-pin.	1 1	Contractor	R. A. F.
20	250 watt...	Electric kettle.....	1	.....do....	Do.
21	....	Bifurcating box...	1	R. A. F...	Do.
22	....	Inspection lamps..	2	.....do....	Do.
23	As reqd...	Cables, cleats, packing and terminal blocks.	....	Contractor	Do.

Instruments: The following instruments are to be fitted in the cockpit in accordance with the requirements of the director of research. These instruments will be supplied from R. A. F. stocks on payment unless otherwise stated.

Item.	Description.	Number.	Type.	Remarks.
1	Air speed indicator......	1	Mk. IV a..	
2	Aluminum tubing for A. S. I.	5	$\frac{1}{16}$ inch....	12-foot 6-inch lengths.
3	.....do...................	2	$\frac{1}{4}$ inch.....	3-foot lengths.
4	Rubber tubing for A. S. I.	2	....	5-foot lengths with screws.
5	Aluminum tube clips for A. S. I............	24	....	
6	T pieces for A. S. I......	2	....	
7	Altimeter................	1	Mk. Va...	0 to 20,000 feet.
8	Cross level..............	1	...do.......	
9	Revolution indicators...	2	Mk. VI...	On engine nacelle.
10	Flexible drives..........	2	....	9-foot lengths.
11	Radiator thermometers.	2	Mk. I a..	22 capillary.
12	Air-pressure gauge......	1	Mk. V.....	0 to 5 pounds.
13	Oil-pressure gauge.......	2	Mk. VIIO.	0 to 60 pounds.
14	Petrol level gauge........	....	....	In tanks.
15	Petrol flow indicator....	1	....	T. D. prismatic, Dewrance, contractor supplies.
16	Watch and holder.......	1	Mk. V.....	Fitted by sqds.
17	Lighting set.......sets..	2	Mk. III...	
18	Fire extinguishers.......	2	Pyrene....	Do.
19	Compasses...............	2	253.........	Contract loan.
20	Pilot's safety belts......	2	....	

7. *Disposition of crew and equipment.*—The two pilots are to be accommodated in the nose, side by side, and are to be provided with full dual control.

Racks for two stretchers are to be fitted on the side of the cabin opposite to the door.

The racks are to be so arranged that there is sufficient lateral space to allow of lifting the stretchers on the racks without tilting them.

Top racks are to be of sufficient height to allow reasonable headroom to the patients seated under the stretchers.

A door is to be cut in the front of the luggage compartment under the pilot's cockpit, allowing of the loading and removal of the stretchers.

Suitable runners are to be fitted on the floor to facilitate sliding the stretchers into the cabin.

A lavatory pan is to be provided. This must be of approved type fitted with an antisplach device, and a cover which is an accurate fit. The lavatory must not flush into space, but must have an easily removable container. The flushing pump is to deliver 2 pints uniformly distributed round the circumference of the pan, at a pressure of 40 pounds per square inch.

A tank with a capacity of 5 gallons is to be provided for flushing water.

A suitable curtain is to be arranged round the lavatory pan.

A drinking-water tank with a capacity of 5 gallons is to be provided at the forward end of the cabin. The top is to be sufficiently accessible for the filling of chatties and "Sparklet" siphons.

Stowage space is to be provided in lockers under the pilot's cockpit for the storage of 60 pounds of food. The lockers are to have sliding panels giving access direct from the cabin.

An ice chest of "Iceland" pattern is to be fitted under the pilot's cockpit and is to be provided with suitable runners.

Access should be by a hinged front cover, and the cold chamber is to be divided into two parts, one of which is to contain 2-quart size "Sparklet" siphons. and one "Aladdin" gallon heat-retaining jar.

A cupboard and bottle rack is to be provided at the aft end of the cabin.

Nine seats are to be fitted in the cabin. These are to be of deck-chair type with folding arm rests, and are to be arranged to give enough leg room for comfort during a long flight.

The attendant's seat is to be at the forward end of the cabin, and he is to be provided with a folding table for the kettle, etc.

The Triplex windows of the commercial Vimy are to be replaced by gauze and are to be fitted with blinds of sunproof material.

Scoop ventilators are to be fitted at the front end of the cabin, on each side. They are to be so arranged that the slip stream is deflected to give adequate cabin ventilation when the aircraft is stationary on the ground. The inlets are to be covered with jute sacking or other similar material, and a syringe is to be provided for the purpose of spraying the sacking.

As much door space as possible is required for rapid evacuation in case of emergency.

Two axes capable of cutting through the cabin walls are also to be provided, one at each end of the cabin.

The fitting of the medical equipment is to be subject to the inspection and approval of the director of medical services.

8. *Miscellaneous.*—Adequate provision is to be made for towing and handling on the ground.

A sufficient number of holding-down rings are to be fitted to the lower planes for the purpose of securing the aircraft in the open.

As far as possible the aircraft is to be interchangeable with the service type Vimy.

The dope scheme to be used is:

Five coats A. M. A. dope to B. E. S. Specification 2D100.

Two coats protective covering P. C. 12—B. E. S. Specification.

Two coats protective covering V. 84—D. 103.

Red crosses on a white ground are to be painted on wings and fuselage as on the experimental aircraft.

All Class I and II modifications approved for the service Vimy are to be embodied.

The undercarriage is to be moved forward and the tail skid pivot strengthened as on the experimental aircraft.

The following particulars are to be stenciled in a conspicuous position on the side of the fuselage:

Weight bare with water...............	—— lbs.
Fuel and oil..........................	1,340 lbs.
Total maximum permissible flying weight............................	12,500 lbs.

August 17, 1921.

BOLTON & PAUL.

Bolton & Paul built a great number of Sopwith machines during the war, and have now turned their attention to all-metal construction.

Their most interesting machine, however, is a stick and wire machine known as the P–8. It is a convertible passenger, mail, or bombardment machine. Its characteristics follow:

Crew: Pilot and seven passengers.
Mail: 500 pounds.
Engines, 2 Napier Lion, water-cooled, fitted with four-bladed propeller 9 feet 6 inches diameter; performance: 450 horsepower.
Ground speed: 149 miles per hour.
Speed at 10,000 feet: 143 miles per hour.
Speed at 15,000 feet: 138 miles per hour.
Ceiling: 25,000 feet.
Climb to 15,000 feet: 15 minutes.
Weight, machine empty: 5,170 pounds.
Fuel: 840 pounds.
Load: 1,870 pounds.
Total weight: 7,880 pounds.
Load per square foot: 10.5 pounds.
Weight per horsepower: 8.75 pounds.
Gas: 100 gallons.
Oil: 12 gallons.
Endurance, loaded, at 10,000 feet: 2¼ hours.
Span: 60 feet 4 inches.
Length: 40 feet.
Height: 12 feet 4 inches.
Gap: 6 feet 6 inches.
Chord, top: 8 feet.
Chord, bottom: 6 feet 6 inches.
Area, wing: 770 square feet.

This machine was designed in 1918 by the Bolton & Paul Co. and is of the single centralized fuselage type. It has both bottom and upper counterbalanced ailerons. The two Napier Lion engines are set in the lower wings at the first strut station, out from the fuselage.

A wide track twin-wheel landing gear has been provided with the landing gear vees extending from underneath the first lower wing strut station. The axles extend from the wheels and are hinged upward on the bottom fuselage longerons.

The stabilizer, elevators, rudder, and fin are of the conventional monoplane type. This machine has very remarkable performance.

The new twin-motored all-metal machine that is being built by the Bolton & Paul Co. for the Air Ministry is practically identical in physical characteristics with the P-8 except for an extra wheel set forward to prevent nosing over.

SHORT BROS. ALL-METAL PLANES.

The Short Bros. Aircraft Co. are the most important exponents of all-metal construction in England. Their newest ship, called the *Silver Streak*, is typical of their methods, so it will be given a detailed description, which should suffice to explain the practices and principles employed.

"SILVER STREAK" ALL-METAL AIRPLANE.

Characteristics of this machine are as follows:

- Engine, Siddeley Puma: 150 horsepower.
- Area: 370 square feet.
- Span: 37 feet 6 inches.
- Length, over all: 26 feet 5 inches.
- Height: 10 feet 6 inches.
- Gas-tank capacity: 50 gallons.
- Oil: 6 gallons.
- Weight, empty: 1,865 pounds.
- Pilot and 400 pounds of freight, or pilot and passengers—weight fully loaded: 2,700 pounds.
- Maximum speed: 120 miles per hour.
- Cruising speed: 90 miles per hour.
- Climb, 10,000 feet: 11 minutes.
- Range at full speed: 360 miles.
- Range at cruising speed: 450 miles.
- Load per horsepower: 10.5 pounds.
- Load per square foot: 7.5 pounds.

This machine is the only British all-metal machine employing duralumin. The system of all-metal construction in this machine embodies the composite use of duralumin and steel. These metals are best adapted to the particular purposes of airplane construction. Nonrustable steel is employed wherever weight allowance permits of suitable thicknesses being used, combining local and comprehensive strength with a reasonable margin of safety. Steel is used, therefore, for the main spars, compression strut wiring, lugs, flying wires, and in the parts most heavily stressed in the wings.

In the main planes and the tail planes the ribs and covering are of duralumin. All the control levers and the landing gear are of steel.

The wing spars are of steel tubes of standard dimensions and the use of these tubular spars enables a thickness of metal to be used which gives them inherent properties of rigidity and strength. The ribs are cut out of flat sheets and slotted and flanged by press tool operation.

The covering of the planes is made up of separate duralumin panels about 12 inches wide. Any of these can be removed and replaced without disturbing the remainder.

The fuselage is constructed wholly of duralumin. The simple form of fuselage is constructed of flat sheets of duralumin fitted on in different shapes and offering a perfect stream-line surface. No internal bracing wires or small fittings are used. The strength of the fuselage is uniformly distributed over its whole area, in consequence of which concentrated points of stress are avoided. This makes it less vulnerable in vital spots to riddling by bullets or shell fire. It allows of an admirable shape for dealing with bending or torsional stress. The fuselage is stiffened by a complete set of duralumin annular channel ribs economically spaced from nose to tail.

Twenty-five or thirty longitudinal duralumin channel stringers are attached in a radial sense the complete length of the fuselage. This form of longeron allows of a smooth surface around the whole fuselage and also permits a distribution of stress to the entire shell.

The engine compartment is built up of duralumin bulkheads which support a tubular engine bed frame proper.

The undercarriage is a combination of pneumatic springs with Oleo shock absorber, eliminating the use of rubber suspension.

A fireproof bulkhead is mounted between the engine and the pilot's compartment. A nose radiator has been fitted to this machine. As a whole, this all-duralumin fuselage represents a very clean job and a minimum of head resistance.

THE SIDDELEY CO.

The Siddeley Co., of which Maj. F. M. Green is chief engineer, has designed and built the following interesting airplane equipment: First, the Siddeley Siskin single-seater fighter; second, the Siddeley Jaguar, 14-cylinder, 350-horsepower, radial, air-cooled engine; third, the Siddeley Lynx, 7-cylinder, 175-horsepower, radial, air-cooled engine. The manufacturers' descriptions of these two engines and the Siddeley Siskin follow:

SISKIN AIRLPLANE.

[Type, single-seater fighter. Designed and constructed by Sir W. G. Armstrong. Whitworth Aircraft (Ltd.). Engined by Armstrong Siddeley Motors (Ltd.).]

I. *General.*—The Siskin is a type of single-seater fighting airplane originally designed for and supplied to the British Government. It has since been modified and improved as the result of service experience so that it now represents the most advanced design of this type of airplane that has been produced. It is fitted with the Armstrong Siddeley Jaguar, 14-cylinder, radial, air-cooled engine for which the airplane was originally designed. Some of the earlier models were engined with the A. B. C. Dragonfly.

All the experience gained in the Great War has been embodied in this airplane. It is robustly constructed and the detail work has been carried out with extreme thoroughness and care. The landing gear enables it to be used in rough country. It is pronounced by pilots to be the most controllable airplane they have ever flown.

The vision for the pilot is exceptional. The position of the machine guns, two or three of which can be carried, is such that they can easily be controlled and adjusted during flight.

The performance of the airplane, particularly at high altitudes, is an advance over any other machine carrying the same useful load. Its speed and climb, combined with its unusual maneuvering power, render it the most formidable fighting machine yet constructed.

II. *Type.*—The airplane is of the biplane tractor type having the top plane larger in span and in chord than the bottom plane. The surface of the main planes is 260 square feet and the weight fully loaded is 2,200 pounds. The load per square foot is 8½ pounds. The normal horsepower of the engine is 320. It is capable of developing 360 horsepower at a higher speed. The load per horsepower is just under 7 pounds. The fuselage is of steel tube throughout and braced with tie-rods. This construction is patented by the Armstrong-Whitworth Aircraft (Ltd.). No welding is used in the frame. The construction is such that there should be little deterioration except in the case of a bad accident. Should this occur, the pilot is protected to a great extent by the strength of the steel frame which surrounds him. The wings are of wood with hollow spars of ample section. The interplane struts are of steel. The construction is such that the airplane is extremely easy to erect, a minimum of truing up being required.

III. *Airplane controls.*—The pilot controls the airplane by means of a rudder bar and control column in the usual way. Fore and aft trim is governed by a handle at the side of the pilot working an adjustable tail plane. The airplane is stable when trimmed to fly at its normal flying speed and the controls are light and extremely effective.

IV. *Engine installation.*—The Armstrong Siddeley Jaguar engine is mounted on a pressed-steel frame in such a way that it can be withdrawn from the airplane without removing the carburetor or any other of its parts. The engine cowling is of the simplest possible construction and it is so arranged that it remains on the engine when this is dismounted. All ordinary adjustments to the engine can be carried out without removing any of the cowling. A large door is provided on each side of the airplane so that the gear on the back of the engine is completely accessible.

V. *Fuel.*—Gasoline is fed to the engine from the gravity tank on the top of the frame containing sufficient fuel to run the engine for about three-quarters of an hour. The remainder of the gasoline is carried in a tank inside the body from which gasoline is pumped by a wind-driven pump to the gravity tank. By this means the gravity tank is kept full so long as there is gasoline in the main tank. The surplus from the pump drains back into the main tank, first passing a gauge which indicates whether or not it is flowing. The throttle and altitude controls are worked by large levers at the side of the pilot. There is no need to have a lever for the ignition, as this is controlled automatically by a centrifugal governor.

A fireproof bulkhead is mounted between the engine and the gasoline tank and the air intakes of the carbureter are taken well outside the airplane.

VI. *Accommodation for pilot.*—The pilot is placed with his eye in line with the chord of the top plane so that he can see either above or below the plane. By this means he obtains a view of the upper hemisphere which is practically unrestricted. The bottom plane is of narrower chord than the top plane and offers but little obstruction to vision downward. The fuselage is comparatively narrow so that the pilot can get a good view over either side, which is of particular assistance in landing.

VII. *Armament.*—The two main guns can be carried directly over the steel tube longerons of the frame, which are of ample strength to stand the recoil of the guns. A belt box can be fixed across the frame between the two guns with sufficient capacity to take about 2,000 rounds of ammunition. An additional gun, if desired, can be carried on the top plane and this can be arranged so that it is possible to fix it in any position to fire from a few degrees from the horizontal upward. The mounting of the guns makes them particularly accessbile. No armament is ordinarily supplied with the airplane.

VIII. *Load carried.*—The normal load carried by the airplane is 400 pounds, including the pilot but exclusive of fuel and oil. Forty gallons of gasoline and 4½ gallons of oil are carried, which will give an endurance of from one and three-fourths to three and one-half hours according to the speed and altitude.

IX. *Performance.*—Carrying the load specified in the preceding paragraph the speed will be 150 miles an hour near the ground, 144 miles per hour at 10,000 feet, and 130 miles per hour at 22,000 feet. The time to reach 10,000 feet will be 7 minutes; 20,000 feet, 25 minutes.

The greatest height that can be reached carrying full load will be 26,000 feet. The speed at which landings can be made is well under 50 miles an hour.

X. *Landing.*—The airplane is fitted with a patent landing gear which is specially designed to enable the pilot to make safe landings at slow speed without shock to the machine. It is possible to land the airplane in small fields, and the shock of landing even on rough ground is so reduced that the life of the airplane is much increased as against the old machines in which more rigid landing gears were used.

The tail skid of the airplane is of robust design and is arranged so that it swivels with the rudder. By this means the airplane can be steered on the ground even at slow speeds with accuracy.

XI. *Structural strength.*—The airplane is designed not only to have a high factor of safety but also to be as safe as possible if damaged by enemy fire. A complete system of bracing is provided to the lower plane in such a manner that the load of any wire can be taken by two other wires if it should become broken. More than this, a wing can be shot away without the airplane collapsing in flight as each plane is supported by independent bracing. A factor of safety of 6 is provided over the normal flying loads.

XII. *Controllability.*—The control of the airplane has been particularly studied in order that the pilot shall be able to obtain the maximum response from his controls with the minimum of effort. The airplane was flown at the British Royal Air Force Aerial Pageant of 1921 in a mock flight as representative of the latest design of fighting scout and its maneuverability was universally considered to be remarkable. This is of the utmost importance to the fighting pilot whose success in an aerial combat depends largely on his power to outmaneuver his opponents.

It has generally been considered that a maneuverable airplane can not be stable. The Siskin airplane, on the other hand, is stable at ordinary flying speeds, that is to say, it can be flown indefinitely without the use of the control column. This property not only relieves the pilot of anxiety but enables him to have a steady gun platform when firing at his opponent.

XIII. *Equipment.*—

- Two Vickers machine guns and mountings.
- Constantinesco gear.
- Two belt boxes.
- One gun sight.
- Camera equipment, according to requirements.
- Bomb racks and release gear, according to requirements.

The design of the Siskin airplane has been differently conceived than any other craft that was found in Europe. It is a single-bay truss type and the landing axle extends from the outer legs of the center section struts in the top wing to the bottom outer strut points on the lower wing, and the main lift truss wires extend from the bottom wing spar root in the fuselage to the outer strut points on the upper wing. The counter lift truss, however, has been installed extending from the rear leg vees of the landing gear to the bottom outer strut points. The machine in its fuselage and tail unit design resembles very closely the SE–5. This will be understood when it is known that Major Green was one of the original designers of the SE–5.

The whole feature of the truss on the Siskin in its conception was to neutralize as much as possible the effect of gunfire in shooting away a part of the main truss on the machine. For instance, it is quite possible to shoot away the auxiliary lift truss from the landing gear to the bottom wing without crippling the wing truss. It is also possible to shoot away the main truss wires within the wing cellule without completely shattering the wing bracing. It is also possible to shoot away the interplane struts without crippling the main structure. Of course, when I mention the partial crippling of the structure, I mean that enough of the structure has been left so as to allow for sufficient flying to a landing field without injury. It is understood that it would be hardly possible with part of the truss shot away to execute any sharp maneuvers or acrobatics.

This machine is very ordinary in its outline and does not represent the last word in refinement. The guns are placed on the exterior of the fuselage. The machine as a whole is primarily a maneuvering and climbing type, although it has a fairly high speed. The machine's characteristics, by virtue of its speed, climb, and maneuverability, are due principally to its very light motor, thus allowing for a very light machine and giving a light loading per horsepower, giving it a predominance in a measure over other machines of this type, due to its large reserve horsepower. The installation of the motor is very simple and is effectively carried out.

The Admiralty test report on this plane is incorporated in this report.

MANUFACTURERS' DESCRIPTION.

[Armstrong Siddeley Motors (Ltd.). Allied with Sir W. G. Armstrong Whitworth & Co. (Ltd.)]

Radial air-cooled aero engine—175-horsepower, 7-cylinder, type Lynx.

This engine represents the highest point yet reached in the development of the air-cooled aero engine. The design has been the subject of searching tests both on the block and in flight.

The exact price will depend upon the number of engines in the contract. The approximate price will be as follows: Seven-cylinder, 175-horsepower radial air-cooled aero engine, complete with the usual accessories, £950.

The following is the guaranteed minimum performance:

- At normal speed: 1,500 revolutions per minute.
- Horsepower: 175 brake horsepower.
- Gasoline consumption per brake horsepower hour: 0.55 pint.
- Oil consumption per brake horsepower hour: 0.03 pint.
- Weight, complete: 450 pounds.
- Exhaust manifold: 25 pounds extra.

Tests.—Every engine is thoroughly tested before delivery.

Guarantee.—Every engine is sold with a guarantee to replace any parts which fail through defective workmanship or material within a period of six months from the date of delivery.

The Lynx engine is the result of much experimental work. The following are the principal points which are claimed to make it particularly suitable for use on an airplane.

Cooling.—The cooling is beyond criticism and the cylinder design is such that complete freedom from distortion is insured. Such things as broken piston rings or burned valves are unknown.

Oiling.—The oiling system is unique. The big ends of the connecting rods are not only lubricated but are cooled by a generous supply of oil, a small part of which only can get to the cylinders. The engine is particularly clean-running and the oil consumption in flight is well under 1 gallon an hour.

Carburetion.—The carburetion is thoroughly satisfactory and the gas distribution is practically perfect. The engine can be throttled down and opened up rapidly without missing.

Accessibility.—The accessibility is superior to any other engine. Any cylinder can be removed in a few minutes and it is easy to get at all accessories.

Mounting.—The mounting in the airplane will appeal to all airplane designers as a satisfactory solution of a difficult problem. Four aluminum feet are cast on the crank case carried well clear of the engine.

Ignition.—The ignition is by two 7-cylinder magnetos driven off the rear of the engine. Each cylinder is fitted with two spark plugs.

Fuel consumption.—The fuel consumption at full-power test may be as low as 0.525 pint per horsepower hour. The company is prepared to guarantee that the consumption would not be more than 0.55 pint per horsepower hour at full load.

Cylinders.—The cylinders have steel barrels screwed into hemispherical aluminum heads. The latter are thoroughly annealed in order to prevent growth and distortion.

Pistons.—The pistons are of aluminum alloy and are fitted with three compression rings and one scraper ring. The gudgeon pin is of ample size and floats both in the piston and in the connecting rod.

Connecting rod.—The connecting rod system is unique. The master rod proper is separate from the split big end which is designed so that all the rods can be easily dismantled. The wrist pins are floating.

Crank shaft.—The crank shaft is in one piece of exceptional stiffness. It is supported by roller bearings everywhere. The propeller thrust is taken by a single-thrust race, so mounted that it absorbs thrust in either direction. The patented system of double oil circulation cools the crank shaft and big end.

Lubrication.—The lubrication is on the dry sump principle. Any excess of oil is collected in an extension at the bottom of the crank case and pumped back to the tank through a filter. The pressure pump delivers oil to the hollow crank shaft which is drilled with a double system of holes, out and return, so that the oil circulates from the front to the extreme back and to the front again, where it is freely delivered to the timing gear. This system not only keeps the crank shaft and big ends cool but makes the lubrication of the crank pins absolutely sure, as the oil is supplied to them from the out and return lines. A second filter is inserted between the pressure pump and the crank shaft. Both oil pumps and filter are mounted in front of the engine and are consequently quite accessible.

Timing gear.—The timing gear is of the epicyclic type, the cams rotating at one-sixth crank shaft speed. It is mounted entirely on ball and roller bearings. There are two independent cams, for inlet and exhaust. The overhead valves are operated by push rods in front of the engine and rockers mounted on ball bearings.

Induction.—The induction system is composed of pipes radiating from a central chamber containing a fan mounted on the back of the crank shaft. This not only increases slightly the volumetric efficiency but thoroughly mixes the incoming gases and makes for almost perfect uniformity of distribution. The mixture is heated, being jacketed with lubricating oil. This not only serves to heat the mixture but also helps to cool the lubricating oil. The carburetor can be mounted any distance below the rear cover that is desired, by means of a junction piece which can be of any length required. This junction piece can be exhaust jacketed if desired.

Characteristics.—

Number of cylinders: 7.
Bore: 5.
Stroke: 5½.
Normal revolutions per minute: 1,500.
Maximum safe revolutions per minute: 1,650.
Brake horsepower at normal revolutions per minute: 175.
Brake horsepower at 1,650: 190.
Direction of rotation: Left-hand tractor.
Gasoline consumption: 0.525–55 pints per horsepower hour.
Oil consumption: 0.03 pint per horsepower hour.
Weight, dry: 450 pounds.
Weight per brake horsepower: 2.56 pounds.
Diameter over all: 43 inches.

MANUFACTURERS' DESCRIPTION.

[Armstrong Siddeley Motors (Ltd.). Allied with Sir W. G. Armstrong Whitworth & Co, (Ltd.).]

Radial air-cooled aero engine—350-horsepower, 14-cylinder, type Jaguar.

This engine represents the highest point yet reached in the development of the air-cooled aero engine. The design has been the subject of searching tests on the block and in flight.

The exact price will depend upon the number of engines in the contract. The approximate price will be as follows: Fourteen-cylinder 350-horsepower radial air-cooled aero engine, complete, with the usual accessories, £1,550.

The following is the guaranteed minimum performance:

At normal speed: 1,500 revolutions per minute.
Horsepower: 350 brake horsepower.
Gasoline consumption per brake horsepower-hour: 0.55 pint.
Oil consumption per brake horsepower-hour: 0.03 pint.
Weight, complete: 700 pounds.
Exhaust manifold: 40 pounds extra.

Tests.—Every engine is thoroughly tested before delivery.

Guaranty.—Every engine is sold with a guaranty to replace any parts which fail through defective workmanship or material within a period of six months from the date of delivery.

The Jaguar engine is the result of much experimental research work. The following are the principal points which it is claimed make it particularly suitable for use on airplanes:

Cooling.—The cooling is beyond criticism, and the cylinder design is such that complete freedom from distortion is insured. Such things as broken piston rings or burned valves are unknown.

Oiling.—The oiling system is unique. The big ends of the connecting rods are not only lubricated but are cooled by a generous supply of oil, a small part of which only can get to the cylinders. The engine is particularly clean-running, and the oil consumption in flight is well under 1 gallon an hour.

Carburetion.—The carburetion is thoroughly satisfactory and the gas distribution is practically perfect. The engine can be throttled down and opened up rapidly without missing.

Accessibility.—The accessibility is superior to any other engine. Any cylinder can be removed in a few minutes, and it is easy to get at all accessories.

Mounting.—The mounting in the airplane will appeal to all airplane designers as a satisfactory solution of a difficult problem. A steel pressing, which is supplied with the engine, finishes in a flange in which are 16 holes, 25-inch pitch circle. This flange is carried clear of the engine, enabling a simple engine plate to be used.

Ignition.—The ignition is by battery and coil, with a dynamo driven from the engine charging a small accumulator. A switchboard complete with cut-out is supplied.

Fuel consumption.—The fuel consumption at full power on test is as low as 0.525 pint per horsepower-hour. This figure was obtained during an hour's full-speed and full-power trial run at 1,650 revolutions developing 376 horsepower at the conclusion of the test of 50 hours.

Absence of vibration.—The engine is extremely free from vibration at all speeds and on account of its excellent carburetion system is remarkably flexible.

Cylinders.—The cylinders have steel barrels screwed into hemispherical aluminum heads. The latter are thoroughly annealed in order to prevent growth and distortion.

Pistons.—The pistons are of aluminum alloy and are fitted with three compression rings and one scraper ring. The gudgeon pin is of ample size and floats both in the piston and in the connecting rod.

Connecting rod.—The connecting rod system is unique. The master rod proper is separate from the split big end which is designed so that all the rods can be dismantled. The wrist pins are floating.

Crank shaft.—The crank shaft is in one piece of exceptional stiffness. It is supported by roller bearings everywhere. The propeller thrust is taken by a single-thrust race, so mounted that it absorbs thrust in either direction. The patented system of double oil circulation cools the crank shaft and big ends.

Lubrication.—The lubrication is on the dry sump principle. Any excess of oil is collected in an extension at the bottom of the crank case and pumped back to the tank through a filter. The pressure pump delivers oil to the hollow crank shaft which is drilled with a double system of holes, out and return, so that the oil circulates from the front to the extreme back, and to the front again, where it is freely delivered to the timing gear. This system not only keeps the crank shaft and big ends cool but makes the lubrication of the crank pins absolutely sure, as the oil is supplied to them from both the out and return lines. A second filter is inserted between the pressure pump and the crank shaft. Both oil pumps and filter are mounted in front of the engine and are consequently quite accessible.

Timing gear.—The timing gear is of the epicyclic type, the cams rotating at one sixth crank shaft speed. It is mounted entirely on ball and roller bearings. There are two independent cams, for inlet and exhaust. The overhead valves are operated by push rods in front of the engine and rockers mounted on ball bearings.

Induction.—The induction system is composed of pipes radiating from a central chamber containing a fan mounted on the back of the crank shaft. This not only increases slightly the volumetric efficiency but thoroughly mixes the incoming gases and makes for almost perfect uniformity of distribution. The mixture is heated, being jacketed with lubricating oil. This not only serves to heat the mixture, but also helps to cool the lubricating oil. The carburetor can be mounted any distance below the rear cover that is desired by means of a junction piece, which can be of any length required. This junction piece can be exhaust jacketed if desired.

Characteristics.—

Number of cylinders: 14.
Bore: 5 inches.
Stroke: 5½ inches.
Normal revolutions per minute: 1,500.
Maximum safe revolutions per minute: 1,650.
B. H. P. at normal revolutions per minute: 350.
Maximum B. H. P.: 380.
Direction of rotation: Left-hand tractor.
Gasoline consumption: 0.525–55 pints per horse power hour.
Oil consumption: 0.03 pint per horse power hour.
Weight, dry: 700 pounds.
Weight, dry, per B. H. P.: 2 pounds.
Length, over all: 43 inches.
Length, engine plate to back of propeller: 25½ inches.
Diameter, which may be covered by fore cowl: 29 inches.
Diameter, bearer bolt pitch circle: 25 inches.

SIDDELEY CO.—MAJOR GREEN'S THEORETICAL INTERPRETATION OF A NEW MULTIPLE AIR COOLED ENGINE TYPE.

Airplanes have been fitted with two or more engines with a view to increasing the reliability of the power plant and also increasing the total horsepower by using more engines of a given size. This has been done in two ways, either by arranging for each engine to drive its own propeller, as in the usual twin-engines type, or by providing gearing so that one or more engines can drive the propeller or propellers at will.

The disadvantages of the former type are well known. The chief disadvantage arises from the lack of symmetry—one engine stopped, producing a tendency to turn which has to be counteracted. The resistance of the stopped propeller is also considerable. Again, with an engine stopped, the power available for flight is insufficient to fly properly with full load. Apart from these disadvantages the airplane is apt to get rather complicated in its design and the resistance is likely to be comparatively high, due to having the two power eggs and the main body in separate units.

Several attempts have been made to mount two or more engines in such a way that they can drive one or two propellers. During the latter part of the war the Germans attempted to make airplanes of this type with a variety of arrangements. They were extremely clumsy and heavy and of little practical use. We ourselves have designed and constructed gearing to connect four Puma engines to two propellers for the Bristol Aeroplane Co., which they are now fitting into a large triplane.

This gearing was designed with a great deal of care and the weight of the transmission gear proved to be 1½ pounds per horsepower. It is possible that this could be improved slightly by using higher speed engines, but we do not think that it is likely to be done for less than 1 pound per horsepower at best. There is also the inefficiency of the two bevel reduction gears to consider. When it is remembered that the average commercial aeroplane takes as revenue load about 3½ pounds per horsepower, the loss of 1 to 1½ pounds and the decrease of efficiency would seem to make the use of this type of gear impossible.

The German four-engine airplane which we have had the privilege of examining is fitted with four 6-cylinder water-cooled engines driving onto a single propeller, and mounted in the nose of the airplane. This type of gear is simpler than the type which we made for the Bristol Co., but has been carried out in a clumsy way, and the whole installation obviously weighs so much as to make it impossible. Having studied this and other attempts at a solution of the problem, we have arrived at the conclusion that it is necessary to make engines specially adapted for the purpose if the weight is to be kept within reasonable limits. We have tried various arrangements of power units and have at length arrived at a solution which appears to us to have the following advantages:

(a) The increase of weight of the power unit over the lightest possible arrangement, which is a single-unit radial engine, is about one-half pound per horsepower.

(b) The increase of weight over a V type engine as now used for commercial work is less than one-fourth pound per horsepower.

(c) The loss of efficiency as against any other type of geared engine is practically nil.

(d) The risk of breakdown due to the gearing connecting the engines with the propeller shaft is likely to be remote.

(e) The complete power unit is self-contained and is convenient for mounting in an airplane. The position for the auxiliary units, carburetors, magnetos, exhaust pipes, etc., is convenient, and the whole unit lends itself to the design of a low-resistance airplane.

(f) The power unit consists of three separate engines. When getting off the ground all throttles can be opened wide and the engines will run at their full normal revolutions. When flying level at cruising speed the throttles will be shut until the same revolutions are obtained. Should one engine break down, then if the throttles of the remaining two are opened wide, the full horsepower of each engine will be available. By this means it will be possible to carry on at normal cruising speed with one engine completely broken down.

Description of proposed power unit.—The power unit consists of three V type air-cooled eight-cylinder engines. Each engine is complete in itself except that it has no bottom half crank case. The crank shaft is carried completely from the top half of each engine. The three engines are mounted on a single aluminum casting divided up into three compartments, each compartment forming the oil sump for one of the engines. In the front end of this casting is mounted a short propeller shaft driven by a single spur gear. Each engine drives on this spur gear by a pinion mounted loosely on its own crank shaft. This pinion is driven through a free-wheel clutch keyed to the crank shaft. Any engine can be started up from the propeller by means of a friction clutch combined with the free-wheel clutch. The whole unit is carried in front of the fuselage of the airplane from the back of the main supporting casting.

This installation could be made for a large range of horsepowers. Each unit is now of 650 horsepower. The cylinders are similar to those used on the Jaguar engine, 5-inch bore by 5½-inch stroke. Each engine runs at 1,850 revolutions per minute, while the propeller runs at 750 revolutions per minute. All cylinders, valve gears, pistons, connecting rods, crank shafts, cam shafts, magnetos, and carburetors are identical and interchangeable. The estimate of weight is contained in Appendix 1, below.

Cooling.—No difficulty is anticipated with the cooling of these engines. The air is taken into the middle of the V and flows into the passages between the engines. Owing to the position of the cowling, the air is taken from that part of the propeller which is of a diameter sufficient to make a draft even when the airplane is standing, so that it will be possible to run the engines on the ground without danger. The over-all diameter of the cowling is 4 feet 6 inches. The magnetos and carburetors are completely accessible.

Design of a commercial airplane.—Preliminary designs of a complete airplane have been made in which the multiple unit can be used. The airplane is of the usual tractor type with the pilot seated in front of the top plane. The surface of the main planes is 1,100 square feet. The useful load carried is 3,000 pounds. The load per horsepower is just under 15 pounds with three engines working, and just over 22 pounds with one engine cut out. The load per square foot is a little under 9 pounds. An estimated list of weights is given in Appendix 2.

The airplane will fly straight with one engine completely stopped. It will be possible to get off the ground and to reach a height of about 4,000 feet with full load, using two engines only. The cruising speed of the airplane with two engines at 2,000 feet will be 90 to 95 miles an hour. The gasoline consumption at cruising speed will be 3 miles per gallon. Carrying 12 passengers, this is equal to one thirty-sixth of a gallon per passenger mile.

APPENDIX 1.—*Estimated weights of triple power unit—Three 8-cylinder engines 5-inch bore by 5½-inch stroke.*

	Pounds.
Cylinders, complete, 24, at 21 pounds each	504
Pistons and connecting rods, 24, at 7½ pounds each	180
Bearings, 18, at 7 pounds each	126
Crank shafts, 3, at 85 pounds each	255
Crank case, 3, at 105 pounds each	315
Valve gear, 3, at 40 pounds each	120
Induction pipes, 3, at 20 pounds each	60
Carburetors, 6, at 8 pounds each	48
Magnetos, 6, at 16 pounds each	96
Oil pumps, etc., 3, at 20 pounds each	60
Gear and clutches, 3, at 30 pounds each	90
Main casting, 1, at 150 pounds	150
Main gear, shaft and propeller boss, 1, at 100 pounds	100
Exhaust pipes, 6, at 14 pounds each	84
	2,188

Horsepower at 1,850 revolutions per minute, 650.
Pounds per horsepower of complete unit, 3.35 pounds.

APPENDIX 2.—*Passenger air-plane fitted with triple-power unit—Estimate of weight.*

	Pounds.
Useful load, 14 people and baggage	2,800
Gasoline, oil, and tanks for 4 hours, at 95 miles per hour	1,000
Engine unit complete with propeller and starter	2,350
Main planes, 1,070 square feet	1,200
Landing gear	450
Tail unit	200
Main body, complete with controls and seats	1,400
Sundries	250
	9,650

Horsepower, 650.
Load per horsepower, 3 engines, 15 pounds.
Load per horsepower, 2 engines, 22.5 pounds.
Load per square foot, 9 pounds.

ADMIRALTY PERFORMANCE REPORT ON THE SIDDELEY SISKIN AIRPLANE.

Admiralty report No. M. 260.—Summary of tests of airplane No. C/4541, Siddeley Siskin type, single-seater fighter (high altitude).

Engine, ABC Dragonfly, at 1,650 revolutions per minute: 320 horsepower.
Propeller: Two-bladed.
Diameter 2745, pitch 2710.
Diameter 2740, pitch 2126. Wrongly marked.

Military load: 398 pounds.
Total weight, fully loaded: 2,181 pounds.
Gasoline: 40 gallons.
Oil: 4 gallons.
Weight per square foot: 8.8 pounds.
Weight per horsepower: 6.8 pounds.
Speed at 3,000 feet (1,810 revolutions per minute): 146 miles per hour.
Speed at 6,500 feet (1,790 revolutions per minute): 145 miles per hour.
Speed at 10,000 feet (1,765 revolutions per minute): 143 miles per hour.
Speed at 17,000 feet (1,700 revolutions per minute): 136 miles per hour.
Speed at 20,000 feet (1,660 revolutions per minute): 130 miles per hour.
Climb to 10,000 feet (indicated air speed, 75; revolutions per minute, 1,555; rate of climb in feet per minute, 990): 7 minutes, 50 seconds.
Climb to 17,000 feet (indicated air speed, 69; revolutions per minute, 1,535; rate of climb in feet per minute, 540): 17 minutes, 15 seconds.
Climb to 20,000 feet (indicated air speed, 66; revolutions per minute, 1,515; rate of climb in feet per minute, 350): 24 minutes, 15 seconds.
Service ceiling: 23,800 feet.
Rate of climb: 100 feet per minute.
Estimated absolute ceiling: 25,300 feet.
Greatest height reached: 22,700 feet, 35 minutes.
Rate of climb: 175 feet per minute.

General description.
Type: Single-seater fighter R.A.F. Type 1.
Name of contractor: Messrs. Siddeley Deasy Co.
Seating accommodation: Single.
Engine: Type ABC Dragonfly.
Horsepower, at 1,650 revolutions per minute: 320.
Height, over propeller: 9 feet, 9 inches.
Span: 27 feet, 6 inches.
Length: 21 feet, 3 inches.
Seat: Pilot behind rear center section. Upper plane cut away.
Type of controls fitted: Stick, standard handle.
Undercarriage or float arrangement: Special design incorporated with under king-post bracing of bottom main planes.
Type: Two Oleo shock absorbing struts fitted.
Size of wheels: 700 by 100 millimeters.
Tail plane: Adjustable.
Loading—
Surface of main planes: 247 square feet.
Weight per square foot: 8.8 pounds.
Total weight fully loaded: 2,181 pounds.
Weight per horsepower: 6.8 pounds.
Special features: Chassis and main plane structure.
Armament—
Pilot's gun, two Vickers: 88 pounds.
Ammunition: 90 pounds.
Total gun load: 178 pounds.
Miscellaneous gear—
Changing boxes—
Oxygen apparatus } 40 pounds.
Electric heating }
Military load: 398 pounds.
Gun and reconnaissance loads: 218 pounds.
Crew of 1: 180 pounds.
Empty and gross weights—
Weight of machine bare: 1,463 pounds.
Military load less crew: 218 pounds.
Weight of machine in flying trim, empty (actual weight): 1,681 pounds.
Crew of 1: 180 pounds.
Gasoline, 40 gallons, including 1 gallon as dead weight: 284 pounds.
Oil, 4 gallons: 36 pounds.
Gross weight of machine with full load: 2,181 pounds.
Engine—
Type: ABC Dragonfly.
Maker: Sheffield Simplex.
Maker's series No. and W. D. No. 5050—A 60200.
Lubrication system—
System: Pressure.
Oil maker preferred: Wakefield Castrol.
Maximum revolutions and consumption—
Maximum revolutions permitted: 1,750.
Horsepower at these revolutions: 335.
Gasoline consumption: 0.94 pint per brake horsepower hour.
Oil consumption: 0.027 pint per brake horsepower hour.
Exhaust system—
Open except for leads from Nos. 2 and 9 cylinders.
Separate for carburetor muffles.
Lead of exhaust pipes.
Magnetos—
Number: 2.
Make: A. E. 9TB.
Carburetor—
Number: 2.
Make: Claudel-Hobson H. C. 8.
Size of jets: 700 by 710; pilot's, 230.
Radiators—
Type: Air-cooled radial.
Air screws—
Maker's series No.: A. B. 8979.
Drawing number—
Marked: 2710.
Measured: 2126.
Diameter: 240.5.
Fuel capacity—
Gasoline—
Position in fuselage in front of pilot, pressure: 28 gallons.
Position in top plane, gravity: 12 gallons.
Oil: 4 gallons.
Top plane, span—
Maximum: 27 feet 6 inches.
Mean effective: 6 feet.
Bottom plane span—
Maximum: 20 feet.
Mean effective: 5 feet.
Area, top plane: 155.8 square feet.
Area, bottom plane: 91.4 square feet.

Total area of planes: 247.2 square feet.
Lateral control surfaces—
 Top plane: 8 feet 2 inches.
 Chord: 1 foot 6 inches.
 Area: 24.7 square feet.
Longitudinal control surfaces—
 Tail planes, top: 9 feet 6 inches.
  Chord: 1 foot 6 inches.
  Area: 24.8 square feet.
 Elevators, top: 9 feet 6 inches.
  Chord: 1 foot 3 inches.
  Area: 11.4 square feet.
Directional control surfaces—
 Fins: 7.2 square feet.
 Rudders, balanced area, 3.95 square feet: 10.7 square feet.
Rigging—
 Thrust line horizontal—
  Main plane incidence: 4° 35′.
  Dihedral: 3° 30′.
  Stagger: 22″.
  Tail plane incidence—
   Maximum: 5°.
   Minimum: 2°.
 Propeller clearance: 7 inches.

Climbing tests.

Standard height.	Time from start.		Rate of climb.	Rate per minute.	Indicated air speed.	Per cent of standard density.	Petrol consumption.
	Min.	*sec.*	*Ft.-min.*				*Gallons per hour.*
Stationary on ground				1,570		102.5	
1,000 feet		37	1,560			99.4	
2,000 feet	1	15	1,500	1,568	78.5	96.3	
3,000 feet	1	53	1,435			93.2	
4,000 feet	2	35	1,380	1,565	78	90.3	
5,000 feet	3	20	1,305			87.4	
6,000 feet	4	10	1,245			84.5	
7,000 feet	5	0	1,180			81.8	
8,000 feet	5	55	1,120	1,560	76	79.2	
9,000 feet	6	50	1,035			76.5	
10,000 feet	7	50	990	1,555	75	74.0	
11,000 feet	8	55	925			71.7	
12,000 feet	10	0	860	1,550	73.5	69.5	
13,000 feet	11	10	800			67.3	
14,000 feet	12	30	730			65.2	
15,000 feet	13	50	670	1,540	71.5	63.0	
16,000 feet	15	25	610			61.0	
17,000 feet	17	15	540			59.0	
18,000 feet	19	5	480	1,530	68.5	57.1	
19,000 feet	21	25	415			55.3	
20,000 feet	24	15	350	1,515	66.5	53.5	
21,000 feet	27	30	280			51.5	
22,000 feet	31	30	220	1,500	63.5	49.8	
23,000 feet	37	10				48.1	
24,000 feet						46.4	
25,000 feet						44.8	
1,000 meters	2	5	1,420	1,568	78	92.4	
2,000 meters	4	40	1,210	1,565	76.5	83.0	
3,000 meters	7	40	1,000	1,555	75	74.5	
4,000 meters	11	20	790	1,550	73	67.1	
5,000 meters	16	10	580	1,535	70	60.1	
6,000 meters	23	15	370	1,515	67	54.0	

Estimated absolute ceiling, 25,300 feet.

Maximum effective height, 23,800 feet.

Maximum height reached, 22,700 feet in 35 minutes, the rate of climb at this height being 175 feet per minute.

Speed tests.

Standard height.	Per cent of standard density.	Gasoline consumption.	Revolutions per minute.	True air speed.
		Gallons per hour.		*Miles per hour.*
3,000 feet	93.2		1,810	146
6,500 feet	83.2		1,790	145
10,000 feet	74		1,765	143½
13,000 feet	67.3		1,740	141
15,000 feet	63		1,720	139
16,500 feet	60		1,705	137
17,000 feet	59.02		1,700	136
20,000 feet	53.52		1,660	130
22,000 feet	49.82		1,620	125

Stability, controllability, etc.—Stability in all directions is satisfactory, except that directionally, with engine on, "rudder" is very pronounced. With regard to longitudinal stability, the tail plane does not exercise a very marked effect, as with the setting "full" forward, machine can be comfortably flown with engine on or off. Controllability and ease of maneuvering necessary for an airplane of this type are excellent. The landing speed is slow and the machine exhibits no bad flying qualities. Diving is steady, there being no tendency to bunt.

Power unit.—Engine installation and gasoline system have proved satisfactory throughout the trials. Attention is drawn to the "spinner," which is built up around the propeller boss and would necessarily require modification for production purposes. Accessibility is normal.

General construction and design.—In general the radical alterations (or additions) made to the standard method of main plane structure are to be commended. The system of underbracing gives the necessary confidence required by a fighting scout pilot. The undercarriage design with the Oleo struts has given no trouble.

Certain detail designs require modification.—1. Fittings on top longerons carrying V center section struts. The modified design fitted after failure of original fittings is satisfactory.

2. Lugs carrying tail-plane bracing. These have shown signs of bending over. It would be advisable to raise the gauge of these, also the size of streamline wire. The bracing has the required factor of safety, but this size wire requires very careful handling. The lower wires and lugs might also get damaged in taxi-ing.

3. Tail-plane adjustment brackets on front spar require modification to eliminate the slackness and the fouling of the vertical fuselage struts when moved. On the port side this strut will need replacement before further flying.

Armament.—Gun trials have not been carried out at this station. The adjustable gun mounting has been carefully examined and warrants proper firing trials. It is very simple and easy to manipulate, and very accessible. Covers should be provided for the guns for high altitude fighting.

T. M. Barlow,
Major, Chief Experimental Officer,
Airplane Experimental Station.
A. T. Shekleton,
Lieutenant Colonel, Commandant,
Airplane Experimental Station.

Martlesham Heath.

PETRO FLEX GASOLINE TUBING.

The Royal Aircraft Co. has conducted tests on Blaisdell petro flex gasoline tubing which has been found to withstand their fire tests, vibration tests, pressure tests, and immersion tests.

The specifications for this tubing are attached.

This report describes various tests on petro flex tubing to obtain data on its suitability for aircraft use. The tubing is made by the Blaisdell Petro Flex Tubing Co. in lengths of 6 feet, with one-half inch diameter clear bore The special feature of the tubing is an inner lining of 10 to 12 tubes of animal gut drawn over each other, without longitudinal or transverse joints and covered with a casing of two and a half layers of doped fabric. The resulting tubing is shaped to a corrugated spiral form of one-fifth inch pitch and reinforced by winding aluminum wire in the spiral groove formed. The following gives a brief résumé of the various tests to which the tubing was subjected.

Flow tests.—The tubing requires a higher pressure to maintain the same flow as through a plain copper tubing of one-half inch inside diameter. The extra pressure is proportional to quantity Q2.2 for the tubing with external reinforcing wire only.

The maximum additional pressure required to maintain flow through a bend of 180° with 9-inch radius is 2½ per cent.

Vibration test.—Tubing satisfactory for 130 hours when filled with paraffin at 4 pounds per square inch pressure and one end vibrated by a cam of three-sixteenths-inch lift rotating at 1,400 revolutions per minute.

Pressure test.—Tubes after vibration test satisfactorily held 50 pounds per square inch pressure.

Fire test.—The original tubing was completely destroyed by an external fire in 90 seconds. This was due to the highly inflammable dope with which the fabric was impregnated. Another batch of tubing in which the fabric was treated with a different dope burned through in periods ranging from 2 to 4 minutes, though in one special test the outside wrapping was only slightly charred after 15 minutes.

Immersion tests.—The tubing is not affected by gasoline or benzole, but the original tubing was pervious to water. The second batch of tubing tested is treated to be impervious to water.

Joints.—The screwed-in joint supplied with tubing satisfactorily withstood the vibration test, and a direct pull of 200 pounds failed to separate the joint from the tubing.

Weights.—The following table gives the weights of a foot length of three types of tubing:

Petro flex with internal wire, 1¾ ounces } Original
Petro flex without internal wire. $1\frac{7}{16}$ ounces } batch.
One-half inch inside diameter P. R. tubing (without armoring), 2½ ounces.
One-half inch inside diameter copper tubing (20 S. W. G. P.), $2\frac{1}{16}$ ounces.

General.—With the exception of the fire test, the petro flex tubing, together with the special joint couplings, gave very satisfactory results. Given better resistance to fire, the tubing would be eminently suitable for aircraft purposes, as, in addition to its lightness and flexibility, it is truly gasoline-resisting.

SPECIFICATION FOR PETRO FLEX TUBING.

Short lengths of tubing for aircraft gasoline pipes.

Layers of gut:

	umber.
Hog—	
Three-sixteenths inch	4
One-fourth inch	4
Five-sixteenths inch	5
Three-eighths inch	6
One-half inch	8
Five-eighths inch	11
Three-fourths inch	14
Horse—	
Seven-eighths inch	3
One inch	3

Cement.—The tubing is cemented with a mixture of special A. S. skin gelatin, glycerin, and formaldehyde.

Canvas.—Three-sixteenths and one-fourth inch, 4 ounces per square yard. Light cotton wing fabric.

Five-sixteenths inch, two complete laps with one-fourth inch, overlap one-sixteenth inch.

Three-eighths, one-half, five-eighths, three-fourths, seven-eighths, and 1 inch, 7½ ounces per square yard. Heavy cotton fabric. Two complete laps with three-eighths inch, overlap one-sixteenth inch.

Glue.—The adhesive medium between the gut and canvas and between the layers of canvas to be a casein cement to B. S. S. 2 V. 2, as applied to hulls and floats (1,000 pounds).

External finish.—The canvas to be coated externally with pigmented oil varnish (red) to B. S. S. 2 X. 1, and after the external reinforcing aluminum wire is in position a coat of seaplane varnish to B. S. S. X. 17 is to be applied externally to the tubing and wires.

External reinforcing wire.—Three-sixteenths, one-fourth, and five-sixteenths inch, bore tubes: Aluminum 17 S. W. G. or copper 18 S. W. G.; pitch 7½ per inch.

Three-eighths, one-half, five-eighths, three-fourths, seven-eighths, and 1 inch, bore tubes: Aluminum 14 S. W. F.; pitch 4 per inch.

The wire is to be clipped off flush with the end of the last groove.

Assembly.—The root diameters of the various sizes to be as follows:

Size.	Root diameter.	Size.	Root diameter.
¼ inch	$\frac{3}{16}$ inch.	⅝ inch	½ inch.
$\frac{5}{16}$ inch	¼ inch.	¾ inch	⅝ inch.
⅜ inch	¼ inch.	⅞ inch	¾ inch.
½ inch	⅜ inch.	1 inch	⅞ inch.

The tubing is to have plain ends and the limit on the bore of the plain ends is to be one-sixty-fourth inch minus 0.

The corrugated portion in the center is to be 1¾ inches long and equally spaced from each end of the tube.

The over-all lengths of the various sizes to be as follows: Three-sixteenths inch to five-eighths inch, inclusive, 3 inches long. Three-fourths inch to 1 inch, inclusive, 4 inches long.

The beeswax used in manufacture is to be removed from the plain ends of all short lengths of tubing.

Long lengths of tubing for aircraft gasoline pipes.

The above specification applies in reference to material, limits, method of manufacture, except the corrugations, which are continued to the ends of the tubing, the number of layers of gut and the root diameters which are as follows:

Size.	Number of layers of gut.	Root diameters.
Hog:		
$\frac{3}{16}$ inch	4	$\frac{3}{16}$ inch.
$\frac{1}{4}$ inch	5	$\frac{1}{4}$ inch.
$\frac{3}{8}$ inch	8	$\frac{3}{8}$ inch.
$\frac{1}{2}$ inch	11	$\frac{1}{2}$ inch.
$\frac{5}{8}$ inch	14	$\frac{5}{8}$ inch.
$\frac{3}{4}$ inch	3	$\frac{3}{4}$ inch.
$\frac{7}{8}$ inch	3	$\frac{7}{8}$ inch.
Horse:		
1 inch	4	1 inch.

Tubing for ground equipment.

The above specification applies in reference to material (except the internal and external reinforcing wire and number of laps of canvas), limits, method of manufacture.

The external reinforcing wire is to be galvanized-iron wire, 12 S. W. G.

The internal reinforcing wire is to be lead-coated-iron wire, 15 S. W. G.

Canvas, four complete laps, with three-eighths inch overlap, one-sixteenth inch.

The root diameters and corrugations to be the same as for long lengths of tubing.

End connections for ground equipment tubing will be specified as required.

REID CONTROL INDICATOR.

This control indicator is an instrument manufactured by Vickers (Ltd.), and is designed to indicate to the pilot the three possible deviations from a straight course. It is intended for flying in fogs, clouds, or at night. It indicates the speed of the machine, the rate of turn, and the degree of bank of the machine for its rate of turn or rate of side slip.

The instrument gives the necessary control indications required by the pilot to regain control in fog and to maintain a straight course. The strain to a pilot of watching a pointer has been overcome by the use of small electric lamps.

For indicating the bank of a machine the lamps are arranged in semicircular fashion. The top row of lamps is controlled by mercury lights and the bottom row by being synchronized with a gyro. The lights are arranged to operate in accordance with the position of the machine and indicate each deviation. If the machine is turned to the right, the lights in the bottom row indicate outward to the right, and if it side slips to the right, the lights in the top row indicate to the right and outward. The left-hand lights are red; the center lights, white; and the right-hand lights, green. To keep a straight course, the pilot keeps two white lights constant.

The instrument is very sensitive and accurate and has an adjustment for steadying in rough weather. Controls are fitted for putting the instrument completely out of action when not required, and also for adjusting the brilliancy of the lamps.

The face of the indicator is hinged and can be opened easily in the air for inspection or replacing bulbs in case of failure. Spare bulbs are carried inside the instrument.

Approximately 50 sets of these instruments are now being constructed for the R. A. F. and will be given service tests in Mesopotamia in the near future.

SPECIFICATIONS FOR 1,000-HORSEPOWER NAPIER CUB ENGINE.

Number of cylinders: 16.

Arrangement of cylinders: 4 lines on 4 cranks.

Bore: $6\frac{1}{4}$ inches (158.75 millimeters).

Stroke: $7\frac{1}{2}$ inches (190.50 millimeters).

Normal brake horsepower and speed: 1,000 brake horsepower at 1,800 revolutions per minute.

Total swept volume of engine: 3,681.6 cubic inches.

Compression ratio: 5.2 to 1.

Direction of rotation of crank: Anticlockwise viewed from propeller end.

Direction of rotation of propeller: Clockwise viewed from propeller end.

Normal speed of propeller: 752 revolutions per minute.

Type of gear reduction to propeller: Spur gearing.

Lubrication system: Forced to all bearings.

Type of carburetors: Quadruple carburetor case with oil sump.

Mixture control: Hand control.

Fuel consumption per hour: Five pints per horsepower hour.

Type of ignition: Four magnetos.

Direction of rotation of revolution, counterdrive facing driving shaft on engine: Clockwise.

Starting arrangements: Distributor provided for gas starter.

COMMERCIAL AVIATION—LONDON TERMINAL AIRDROME, CROYDON.

I. *Organization.*—The London Terminal Airdrome, Croydon, is a State-owned customs airdrome under the direction of the controller general of civil aviation, and is the principal British air fort for the continental air services. Here aircraft entering or leaving this country can obtain a customs clearance as do ships at seaports.

The airdrome is under the immediate control of a civil aviation traffic officer who is helped by two assistant traffic officers and by wireless, meteorological, and other staff.

The latest types of ground equipment affecting such matters as night flying, meteorological information, signaling, etc., are installed.

Notice board, situated near the customs office, gives full details of machines due to arrive or depart during the day, of those actually in transit and of the times at which airplanes pass over Lympne Airdrome on their way to or from the Continent. A large chart also gives the position of machines in transit, notification of the positions being received continuously by wireless.

A medical orderly is continuously on duty in a fully equipped first-aid dressing station, and the services of a medical practitioner are available at very short notice.

A post office from which letters, telegrams, etc., may be dispatched is situated on the airdrome (near customs office).

II. *Transport services.*—Air transport services to the Continent were inaugurated on August 25, 1919, and have been operated from Croydon Airdrome since March, 1920. These services, which have been carried out by British and foreign companies, have been operated to Paris, Brussels, and Amsterdam.

During 1921 two British companies ran regular services to Paris during the year, and additional British services to Paris and Brussels are sanctioned to begin this spring.

All transport companies operating regular services on the cross-channel routes are in receipt of subsidies from their respective Governments.

In addition to these regular services, special flights for business or private purposes are carried out by British firms to places at home and abroad.

III. *Accommodation.*—(1) Hangars, workshops, etc.: On the west side of Plough Lane, which passes through the station, are hangars, workshops, technical stores, gasoline stores, etc. Certain of the buildings are occupied by Messrs. Handley Page Transport (Ltd.), Messrs. S. Instone & Co. (Ltd.), Messrs. Surrey Aviation Services, Compagnie des Messageries Aeriennes (French), Compagnie des Grands Express Aeriens (French), Koninklijke Luchtvaart Maatschappij (Dutch), and certain other private owners of machines.

(2) Miscellaneous: On the east side of Plough Lane is a garage maintained by Basil S. Poster (Ltd.), and a residential hotel established in Government buildings by Messrs. Trust Houses (Ltd.), for the benefit of travelers, pilots, mechanics, etc.

A level crossing similar to those used on railways is provided over Plough Lane to enable machines to cross from the hangars to the airdrome and vice versa.

(3) Office plots, etc.: Along the main approach to the departure station are situated the passenger and goods offices of the Air Transport and allied companies.

(4) Public inclosure: To enable members of the public to view the arrival and departure of machines on continental service, an inclosure overlooking the landing ground has been provided.

IV. *H. M. customs.*—The customs office is a fully equipped customs clearance station where officers of the customs service are in constant attendance to clear all outgoing and incoming aircraft. Before departure and on arrival from abroad, machines proceed to the continental arrival and departure station, where the passengers and cargo are subjected to the usual customs formalities.

An immigration office, through which all aliens must pass for passport examination, is attached to the customs office and is in charge of the civil aviation traffic officer.

V. *Civil aviation traffic officer.*—This building, which is the headquarters of the civil aviation traffic officer, is immediately beside the customs station in front of the aerodrome and contains various offices required for administration purposes. The duty office is open day and night and records all details of machines landing, arriving, or departing.

VI. *Central control tower.*—Although regular night flying is not yet in operation, a central control tower has been provided. From this point the officer in charge of night flying can control the whole of the night lighting apparatus, and can communicate with machines in the air by means of visual signals or wireless. The tower contains the switches for the electric night landing lights and is connected by telephone with the searchlight posts and wireless station. During foggy weather one of the civil aviation traffic officers is on duty in the tower to bring in machines by means of wireless directions, should the pilot desire such assistance.

VII. *Meteorological office.*—A meteorological office is situated on the aerodrome, from which are issued hourly reports on the weather conditions prevailing on the London to Paris, London to Brussels, and London to Amsterdam routes. These are posted on a notice board at the aerodrome and distributed to the various air transport companies and to the aerodrome wireless station for transmission to machines in the air. Special detail reports to cover any route or time are also issued on demand. Daily forecasts obtained by telephone from the meteorological headquarters at the Air Ministry are also issued.

VIII. *Night flying lights.*—(1) Landing lights: For the purpose of indicating the proper direction in which machines should take off or land by night, landing lights are provided in accordance with the international air convention. These are arranged in the form of two L's, back to back, the short arms of the L's being at right angles to the direction of the wind.

The lights consist of electric lamps below thick glass covers, flush with the ground, so arranged on the airdrome that the L's can be displayed to indicate the prevailing direction of the wind. In the event of a change of wind, the lights can be altered immediately from the control tower to conform with its new direction.

(2) Local pilotage (cone) light: In order to assist pilots in locating the airdrome at night, a new and distinctive form of aerial lighthouse, known as the local pilotage (cone) light has been installed on the airdrome. This light has two parts, one a flashing lamp and the other a brightly illuminated cone, apex uppermost, which is conspicuous from all directions. It is semiautomatic in operation, an electric switch in the control tower actuating it, and is visible from a distance of about 12 miles.

(3) Searchlights: Three 36-inch searchlight projectors, connected by telephone to the control tower, one at each corner of the airdrome, are installed for the following purposes:

To throw upward fixed beams so that at night aircraft may locate the airdrome.

To light up machines which may have broken down on the airdrome and enable work on them to be carried out during the night, and thus "clear" the airdrome by morning.

To aid aircraft to land at night by throwing a widely divergent light across the airdrome.

(4) Obstruction lights: All high buildings overlooking the airdrome, including the wireless masts, are marked with red obstruction lights as a guide to pilots flying at night.

IX. *Pyrotechnic signals.*—Rocket and Very lights are also used for signaling to and from aircraft in accordance with the International Air Convention.

X. *Compass swinging.*—A compass swinging base installed on the airdrome is available to facilitate the correction of compasses and the services of an expert compass adjuster are available day or night.

XI. *Wireless telegraphy, telephony, and direction finding.*—Wireless plays an important part in the service of commercial flying. It provides an efficient and speedy means of communication for:

(1) The distribution of meteorological information.

(2) Messages from one airdrome to another, i. e., notification of arrivals and departures of aircraft, forced landings, etc.

(3) Ground to air signals.

(4) Navigation of aircraft in flight.

The Air Ministry is the center of the meteorological service and receives, by wireless, weather reports from all parts of Europe. These are passed to the meteorological section, where a collective report is prepared and broadcasted by wireless four times daily.

On the British section of the London-Paris route the wireless stations are at the London Terminal Airdrome, Croydon, and at Lympne (Folkestone).

On the French section the wireless stations are at St. Inglevert (near Calais) and Le Bourget, the Paris Terminal Airdrome.

Haren (Brussels) and Soesterberg (Amsterdam) are the Belgian and Dutch stations, respectively.

The only class of message dealt with are those directly concerned with the service of aircraft; personal messages are not accepted.

The installation at Croydon may be regarded as an up-to-date example of wireless apparatus in that it embodies the latest ideas and developments of wireless research in radio telephony, telegraphy, and direction finding.

XII. *Routine.*—On the departure of an aircraft its name and destination are reported to the duty officer, and a message is written by him in the following form:

Instone G. E. A. S. I., Pilot Jones, 8 passengers, 16 packages, 3 bags mail, left 1635.

If the airplane is going to Paris, the message is addressed to "Commandant, Le Bourget." It is passed by land line to Air Ministry wireless station, from which it is transmitted to Le Bourget. The Croydon station is thus left free to work with aircraft.

The average time taken between the departure of an airplane and the receipt of the wireless message by the commandant, Le Bourget, is 11 minutes.

COMMERCIAL AIRCRAFT TRANSPORTATION BETWEEN ENGLAND AND FRANCE.

Croydon, the main commercial airdrome of England, is situated 12 miles from London. The air lines running between Paris and London operate between Croydon in England and Le Bourget, which is 12 kilometers outside of Paris.

Each passenger is allowed to carry 15 kilograms of baggage and is required to have his passport viséed on arriving at the airdrome. The passengers at each airdrome must also present their hand baggage for customs inspection.

Both Croydon and Le Bourget have meteorological stations. Every hour from 7 a. m. to 6 p. m. wireless weather reports are received from all the different airdromes situated along the line between Paris and London. These are Beauvais, Abbeville, Le Crotoy, St. Inglevert, Lymne, and Tonbridge. These weather reports are reproduced hourly on the meteorological chart which is posted at the gate of the airdrome for general observation and information purposes. They are available for both pilots and passengers. This chart gives the barometric pressures, temperatures, and wind velocities, wind direction, and the nature of the sky—cloud formation, presence of fog, etc.

To render these weather observations for different points more clear, a ground chart representing France and England is placed on the side of this main characteristic chart, indicating the visibility and general weather conditions by colored disks at all the different points. A blue disk indicates a clear sky, a blue and gray disk represents a semiclear sky, a gray disk represents a cloudy sky, a black disk represents rain, a white disk with black spots represents snow, a yellow disk with an arrow represents a mist, a yellow disk with a cross represents a heavy fog, and a red disk represents a storm. Smaller white disks with significant numerals indicate the visibility in kilometers. The direction of the wind is indicated by an arrow pointed in the direction of the wind, and the number of barbs on the tail of the arrow indicate the force of the wind, each one of these barbs representing 2 kilometers. This ground chart and the meteorological table are placed in front of the aerial navigation control office.

The character of the weather, whether rain, storm, or sunshine; the visibility, direction, and velocity of the wind are all thus characterized by the several disks with the indicative arrow and are thumb-tacked to the geographical position on the ground observation point along the route which the plane will fly.

On another chart situated to one side of this meteorological chart are placed small, 1 : 100 scale, tin airplanes with national commercial air-line identification number of the airplane, and located or thumb-tacked at the different points along the route on this map at which these aircraft are situated in their flight from station to station. As the aircraft transport passes over different air ports along the route, between Croydon and Le Bourget, their position is wirelessed to both stations and the position is shown on the board.

All aircraft are operated on schedule time. The schedules are published in a small booklet called Aero Indicator, which is published under the auspices of the Undersecretary of State for Aeronautics and Airplane Transportation Department in France. These time-tables are very similar to train time-tables and are profusely illustrated with maps, instructions, duties, distances between stations, times of arrival and departure, postage rates, express rates, etc. Monthly, a smaller edition of this Aero Indicator is published for distribution, showing any changes of schedule or information given in the larger edition.

GENERAL.

CONCLUSIONS ON TECHNICAL REPORT.

The aeronautical activities of France, Italy, Germany, Holland, and England have been considered in this report from a technical standpoint. An effort has been made to abstain from making any comment in presenting the outstanding features of aeronautical development in each country in order that the development might be shown in an unbiased way.

Based upon experience and the information procured on this inspection trip, some recommendations have been made as to design of airplanes and motors, metal construction, fuel systems, motor mounting, landing gears, wheels and tires, propellers, thermostatic control, bomb racks, Servo motors, and wireless, and a list of equipment which it is believed would be advantageous for the American Government to purchase abroad has been prepared.

In making these recommendations and drawing these conclusions, no attempt is made to discuss relative merit. The facts have been presented as fully as possible and all the information that could be procured has been incorporated. Opinions have been formed after weighing the relative merits of the development in each country.

GENERAL RECOMMENDATIONS.

DESIGN.

Corrections and interpretations should be established as to minimum load strength factors required in all parts of the airplane structure. This would require more accurate knowledge of the unit loads imposed in all the different evolutions of flight for all the different types. This is absolutely necessary for the immediate and efficient design of aircraft from a structural weight standpoint in view of the various and diversified interpretations and assumptions of the different Air Service engineers with respect to their structural requirements.

AIRPLANES AND MOTORS.

We should purchase as soon as possible (in interpretative form to our multimotored bombardment specifications) the latest Junker 4-Liberty motored, all-duralumin, internally braced monoplane for service test, type adaptation purpose, and observation of this type of construction for educational purposes.

The landing gears should be of the Oleo type. Wheel controls should be installed on all multimotored types and all control surfaces should be compensated. Wings and fuselage should be designed in demountable fashion with the minimum number of couplings. The two wing tips should disengage from the centralized wing unit or center section supported to the fuselage and holding the load, power plant, etc. The fuselage should be detachable at the rear of the main wings, this to render more easy ground hand maneuvering and housing in case of repairs or housing in hangars.

An observation and torpedo-carrying type of airplane should be designed for the model "W" McCook Field, engineering division, 750-horsepower type, 18-cylinder engine.

A single-motored night bombardment type should be powered with a 600 Packard or model "W" engineering division type of engine and our future multimotored bombardment types should be designed around the Liberty Packard 600 or model "W" engineering division engines.

The development in a convertible multimotored type of a troop-carrier and ambulance plane should be undertaken as one of our new types.

A pursuit plane should be designed for the Siddeley Jaguar or Bristol Jupiter type engine. This should be of the climbing and maneuverable type, to ascertain at first hand the advantages of adoption of an analogous type of power plant for one of our types of pursuit planes. The design and development of a suitable air-cooled radial engine of 400 horsepower for pursuit planes and having a diameter of about 45 to 50 inches should be hastened. This motor should not weigh over 2 pounds per horsepower and should be further developed with an auxiliary supercharger for high-altitude work.

Further development work should be carried on with the shock-absorbing mount for the 300 Wright motor.

The Rateau type supercharger should be tried on a new pursuit design.

Single-seater armored pursuit planes should be of the monoplane semiinternally braced type. The controls should be designed in such fashion as to make them absolutely separate and independent in their connections with respect to either aileron. They should have independent circuits so as to allow the aviator to disengage either one or the other of the ailerons at will and still have an aileron under control in case of injury by gunfire. The same should be done with the elevators.

METAL CONSTRUCTION.

It will be absolutely necessary for us to develop military airplane types in all-metal construction. Metal airplanes as evidenced in Europe can be classified under the following categories:

1. The Fokker type, embodying welded steel tube fuselage, welded steel tube landing gear, welded steel tube tail surfaces, and wooden wings.
2. The Junker type, embodying duralumin multiple spar wings, steel landing gear, duralumin frame, and duralumin covering for wings, fuselage, and tail surfaces.
3. Dornier type, embodying alloy steel trellis type wing spars with duralumin ribs and duralumin covering, duralumin frame, duralumin covered fuselage and tail surfaces, and duralumin landing gears.

4. Breguet type, embodying duralumin tube and steel fitting fuselage construction, duralumin and steel fitting landing gear, duralumin spar and wooden rib wing construction.

5. Wibault type, embodying duralumin tubing and steel fitting fuselage in Breguet fashion with Breguet type tail. but with steel landing gear, duralumin spars and ribs in fabric-covered wings.

6. Short type, embodying duralumin-covered fuselage with annular duralumin channel ribs and channel stringers, duralumin tail surfaces and wings of alloy steel tube spar, duralumin rib and duralumin-covered construction.

These represent the principal combinations and adaptations of metal construction which are representative of foreign practice and from which we can deduce the best types for our future all-metal construction.

WINGS AND FUSELAGE.

On our training, pursuit, and day observation single-motored aircraft I would recommend the adoption of welded steel tube fuselage, tail surfaces, and landing gear. Mild steel should be used with fabric-covered fuselage and tail surfaces. For the wing constructions I would advocate the construction of wooden wings for experimental purposes. Our development of sheet-metal types of adaptable wings could be carried along in experimental fashion for application to these machines when the wings are fully developed and proven.

However, experiments should be carried out immediately for the development of wings similar to the Wibault all-metal type with fabric covering and the Dornier metal-covered type. In the Wibault system we should employ alloy steel spars, duralumin ribs, and fabric covering. In the Wibault system we would have the experience of developing an all-metal wing with the major stressed parts of alloy steel and an all-metal wing construction with fabric covering. This would give the advantage of ready inspection in the field and in manufacture and would permit changing of fabric covering without detracting from the inherent properties of all-metal construction. In the Dornier system we would have an all-metal wing using alloy steel spars, duralumin ribs, and steel fitting. A fuselage with duralumin covering should be designed. This would be applicable to some of our internally braced construction or in the conventional Pratt truss type. These two types of wings could be applied to any of our military types. The advantage in developing both the Dornier type wing construction and the Wibault type wing construction would be that we would have perfected metal wings both with and without duralumin covering.

The first recommendation is for welded steel fuselages. However, other desirable types of skeleton fuselages should be developed of the duralumin tube and steel fitting type or of the alloy steel tubing type.

On the larger multimotored monoplanes of internally braced construction with metal covering the Junker type of internally braced construction either in multiple spar fashion as in the JL type or in the two-spar internally braced type as in his latest four-motored, passenger-carrying plane which is now being constructed, is recommended. Fuselage should likewise be either of the Junker type of construction or of the duralumin type and steel fitting, alloy steel tube, or welded steel tube types of construction. This is to be absolutely determined with regard to the relative advantages of accessibility, maintenance, shipment, or consideration of housing in the field. If the machines are of such proportions that they are too large to be housed in standard hangars, they should be of the all-duralumin-covered types of construction.

FUEL SYSTEMS.

When practical, gravity gas-tank feed should be used.

All future fuel systems should be provided with an auxiliary hand feed pump of large capacity from service to gravity tank on all bombardment types of aircraft. This would insure replenishment of gravity feed gasoline in case of failure of the fan-driven pumps. Development should be continued on the fan-driven centrifugal type gasoline pumps.

Service gasoline tanks should be detachable on single-seater pursuit aircraft in lieu of the development of satisfactory resistant covered tanks to resist crashes and incendiary and spotlight ammunition.

Gravity gasoline tanks, however, on pursuit planes, should be of the crash-proof type.

The excess gas required under the new specifications for single-seater pursuit planes over that of combat load should be carried in removable tank, absolutely segregated from any internal integral part of the fuselage structure so as to minimize to the greatest extent the excess cargo space to be provided for in the basic structure of the pursuit airplane. This permits advantages of aerodynamic outline and insures better vision. If this is not done, the structural limitation will cut down performance on account of placing the added gas load.

It is recommended that pursuit planes have a total gasoline capacity of three hours with three-fourths of an hour's fuel in a removable tank. This would permit the design of a ship with two and one-fourth hours' basic fuel capacity. The three-fourths hour fuel supply, it is understood, will be in field removable tanks.

If possible, gas tanks should be placed on the main wing on multimotored machines.

MOTOR MOUNTS.

All motor mountings should be of the easily demountable type with a minimum number of connections so as to facilitate the changing of motors in the field.

LANDING GEARS.

Oleo landing gear development should be pushed vigorously and the purchase of several of these Oleo gears for adaptation to some of our existing types will overcome inertia at least in the development of this type. Our designers and engineers in the field would see the practicable adaptation and feasibility of such types as exist abroad.

On large bombardment multimotored types the main chassis wheel should be placed as near the center of gravity

as possible to facilitate handling on the ground by ground crew; and auxiliary wheels to prevent nosing over should be installed immediately forward but not carrying the load of the airplane while taxi-ing.

WHEELS AND TIRES.

New tires and new wheels should be developed for large bombardment type machines for use in soft, sticky, muddy ground.

PROPELLERS.

Experiments toward the simplification of steel propellers should be carried out with a view to making them easier to manufacture. Our first lesson can be well drawn from the Siddeley interpretation of this type with tapered gauge blade construction.

THERMOSTATIC CONTROL.

Thermostatic temperature control should be developed for our future huge multimotored aircraft, employing three or more motors.

BOMB RACKS.

All bomb racks should be inclosed in the fuselage.

SERVO MOTORS.

Experiments should be carried on for the development of Servo motors for aiding in control of huge bombardment multimotored machines of the near future.

WIRELESS.

Wireless cabins should be installed on all our large bombardment types and in passenger-carrying aircraft.

PURCHASE.

Recommendations of articles to be purchased in Europe follow under next heading.

RECOMMENDATIONS OF ARTICLES TO BE PURCHASED IN EUROPE FOR THE UNITED STATES AIR SERVICE EXPERIMENTAL STATION AT M'COOK FIELD.

It is recommended that the following aircraft and articles of aeronautical equipment be purchased in Europe for study and test by our engineering division for the purpose of determining their value for adaptation of principles in the solution of our problems. Negotiations for some of this equipment may already be under way. These purchases should be made after conference with the chief of our engineering division.

France:
- (1) Breguet sesquiplan.
- (2) Wibault bombardment plane.
- (3) 600-horsepower Renault.
- (4) Rateau supercharger for Hispano-Suiza engine.
- (5) Lamblin radiators.

Germany:
- (1) Junkers new monoplane, with 4 Liberty motors.

Holland:
- (1) Fokker observation plane.

England:
- (1) Siddeley Jaguar, 14-cylinder, air-cooled, radial engine.
- (2) Vickers hand fuel pump.
- (3) Vickers centrifugal fan-driven gasoline pump.
- (4) Reid flight indicator.
- (5) Experimental adaptation of Handley Page type wing.
- (6) Cook drift sight.
- (7) Siddeley steel propeller for Liberty engine, DH-4.
- (8) Rolls-Royce Condor, 600-horsepower, 12-cylinder engine.
- (9) Napier Cub, 1,000 horsepower engine.
- (10) Bristol Jupiter.
- (11) Siddeley Oleo landing gear for Martin.
- (12) Bristol Oleo landing gear for XB1A.

INDEX.

INDEX TO REPORT OF INSPECTION TRIP TO FRANCE, ITALY, GERMANY, HOLLAND, AND ENGLAND.

TECHNICAL SUPPLEMENT.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV February 15, 1923 No. 392

MODIFIED MARK I AIRPLANE FLARE

(ARMAMENT SECTION REPORT)

Prepared by
Charles Leigh Paulus
Engineering Division, Air Service
McCook Field, Dayton, Ohio
July 19, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

MODIFIED MARK I AIRPLANE FLARE.

OBJECT.

To modify the present Mark I airplane flare so as to give a higher percentage of reliability. This action is necessary because of the fact that the Mark I airplane flares in possession of the Air Service at the present time are of an age which causes their percentage of operation to be very low.

HISTORY.

In view of the fact that an absolutely reliable parachute flare was required by the Airway program, it was decided to rework the present Mark I airplane flares in such a way as to cause the opening of the parachute to be the initial function in the cycle of operation of the flare. This arrangement would eliminate the risk to human life which would otherwise be caused by the Airway pilots flying across country. All work done upon this project was conducted under E. O. 555–74, and if further detailed constructional information is desired it can be obtained through assembly drawing No. X–42369 or Parts List No. 9965 in the Release Section, McCook Field, Dayton, Ohio.

RECOMMENDATIONS.

Due to the fact that all parachute flares tested containing the above-described modifications were entirely satisfactory, it is recommended that all parachute flares used on the Airway project or for use upon airplanes flying at low altitudes be modified according to assembly drawing No. X–42369.

CONCLUSION.

It is concluded that the above-described modifications upon the Mark I parachute flare are necessary in order to use these flares upon airplanes flying at low altitudes or upon airplanes flying cross country in time of peace.

DESCRIPTION.

The Mark I parachute flare as drawn from stock is first totally disassembled. The fins are removed and a copper tube is sweated to the outer wall of the case as shown on photostat No. X–42369. The candle which has been removed from the case is then reworked according to drawing No. X–42370. A 1/16-inch full flexible steel cable 36 inches long is fastened to the upper (parachute end) ring in the steel cable, which carries the candle. The candle is replaced in the outer case in the usual way and the outer case crimped directly in front of and adjacent to the rear mounting station of the flare. The 1/16-inch full flexible cable is threaded through the copper tube previously mentioned in such a way as to allow any surplus to extend through the front end of the tube. The heavy steel supporting cable which is attached to the upper end of the candle is coiled and the disk to which the parachute shroud lines are attached is placed in the center of this coil simultaneously with the foregoing operation. A disk of heavy paper about 4 inches in diameter is placed over this assembly to prevent the parachute or parachute shroud lines from coming in contact with and perhaps being damaged by these metal parts. The parachute shroud lines are coiled into a compact mass, using great care to prevent entanglement. A piece of 3/16-inch diameter woven linen cord about 9 feet long (this cord should have a tensile strength of at least 200 pounds) is inserted through the circular vent in the top of the parachute about three-quarters of its length. The parachute is packed into the case by the use of the zigzag method; that is, the parachute after being closely compressed longitudinally is pressed into place by folding it back and forth across the diameter of the case. A knot is tied in the linen cord at a point where it protrudes through the opening in the top of the parachute, and the cap is replaced upon the end of the outer casing and crimped into place in such a manner as to allow the linen cord to protrude. This is clearly shown in Figure 1. The thin crimping edge around the outer diameter of the cap is crimped under for a space of approximately ½ inch to prevent any damage to the linen cord. The improved firing mechanism shown on photostat No. X–42369 may be screwed into place in the nose of the flare. The fulminate cap should be left in the safety container and tied to the above in every instance except when the flare is ready to be mounted upon the flare rack of an airplane. The fulminate cap is then assembled into the firing mechanism and the 1/16-inch full flexible cable, which is attached to the parachute end of the supporting cable of the candle, is passed through the vernier holes in the body of this mechanism. This action causes the wire to pass through a hole in the firing pin and permits the removal of the safety pin. (This pin consists of a standard cotter pin attached to a steel ring.) The protruding end of the linen cord is securely fastened to the rack which maintains the flare upon the airplane.

Referring to Figure 1, it will be observed that the modified Mark I parachute flare assembly, complete, is shown at the top. The next row across the figure, starting from the left side, contains the rope, which is packed with the parachute in the outer case, the parachute, which is unmodified, the magnesium candle, which has been rejuvenated by drilling four ½-inch holes 4 inches deep in the fuse end. The drillings from these holes are mixed with a 10 per cent (by weight) mixture of flashlight powder. This compound, which is mixed to the consistency of a thick paste by the use of a solvent (alcohol) is tamped lightly back into the drilled holes. The reworked candle is shown on photograph No. 14044. Photograph No. 14049 shows the Mark I parachute flare in the process of modification. Figures 3 and 4 show a bottom and side view of a parachute flare (minus firing mechanism) as reworked at McCook Field.

OPERATION.

The action of the flare upon release is as follows:

The cord attached to the rack cams the cover off and pulls the parachute out of the outer case. The parachute takes air, tightens the shroud lines, and pulls the $\frac{1}{16}$-inch full flexible cable from the firing mechanism. This action causes the fulminate cap to be ignited. This cap ignites the booster and the booster lights the candle. As the booster is discharged the front end of the case is blown or torn off. This permits a flow of oxygen, which burns the thin steel of the outer case simultaneous with the candle.

TEST.

The modified Mark I parachute flares were tested at McCook Field, Dayton, Ohio, in the following manner:

1. Modified flares were used by the Equipment Section as a safety measure during all night tests conducted upon electric landing lights.

2. Flares were released during night flying experiments in order to obtain information as to the reliability of the modification. Although a great number of flares were dropped during these experiments, no malfunction that could be traced to the modification incorporated were encountered.

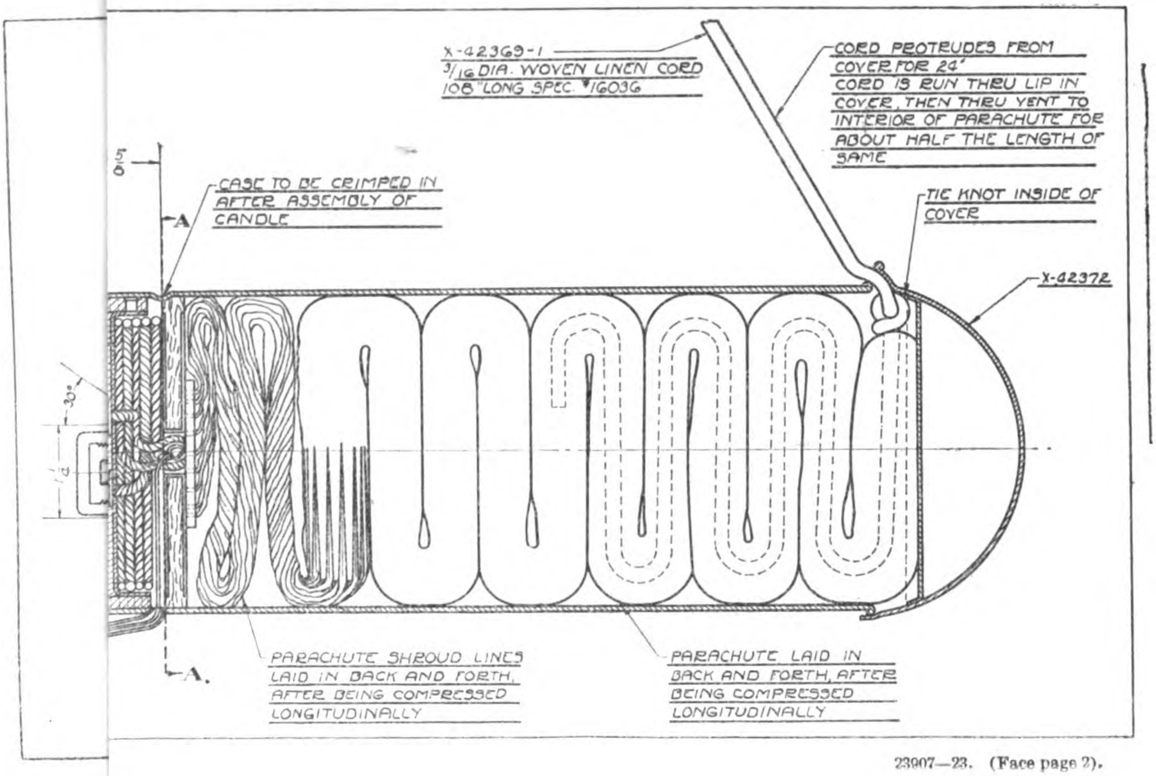
3. A number of modified flares were released in the daytime at altitudes sufficiently low to enable an observer on the ground to observe the complete cycle of operation of the mechanism. During these tests the fact was conclusively proven that the parachute as packed in the modified flare will always open, regardless of whether or not the candle is ignited. This prevents any possibility of a dud flare causing damage to objects upon the ground.

4. During tests conducted upon the mechanism it was found that the parachutes packed in the standard Mark I parachute flare functioned with a higher percentage of reliability as used in the modified flares. This is due to the fact that the initial tension upon the material of the parachute at the release of the flare is much less because it opens almost simultaneously with the release of the flare.

5. The firing mechanism as modified was first ground tested, and it was found during these tests that the fulminate caps although entirely unserviceable as used in the present Mark I parachute flare could be fired with the consistency of approximately 98 per cent by use of a plunger actuated by a spring.

6. During the preliminary experiments upon this project it was found that a high percentage of the malfunction encountered with the present Mark I parachute flare was caused by the fact that the pressure generated by the booster charge was not transmitted through the candle to the parachute, due to dents in the outer case, or swelling of the paper covering, which is used to incase the candle. These malfunctions were entirely eliminated by pulling the parachute from the case mechanically.

7. Various tests conducted upon Mark I parachute flares at McCook Field have conclusively proven that considerable damage may be caused by the finned outer case as it falls in trajectory to the ground. This action was eliminated by removing the fins from the case and by clamping the case to the magnesium candle. This arrangement causes the case to be burned simultaneously with the candle.



23907—23. (Face page 2).

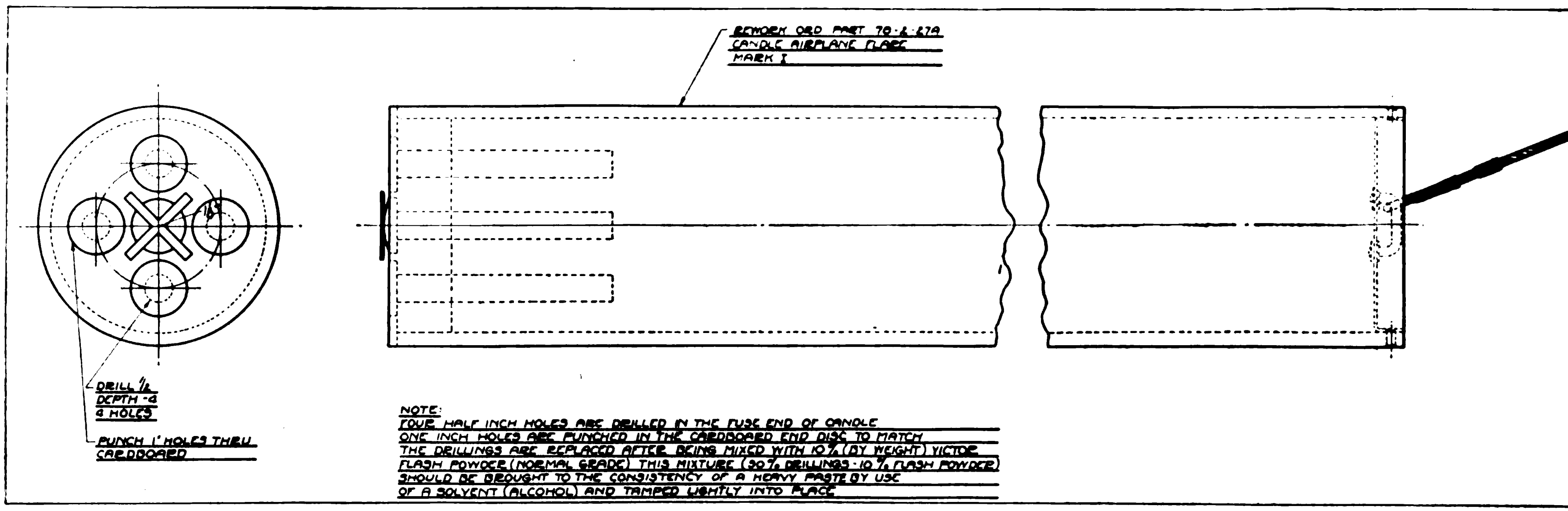

REWORK ORD PART 70-2-27A
CANDLE AIRPLANE FLARE
MARK I
DRILL 1/2
DEPTH 4
4 HOLES
PUNCH 1" HOLES THRU
CARDBOARD
NOTE:
FOUR HALF INCH HOLES ARE DRILLED IN THE FUSE END OF CANDLE
ONE INCH HOLES ARE PUNCHED IN THE CARDBOARD END DISC TO MATCH
THE DRILLINGS ARE REPLACED AFTER BEING MIXED WITH 10% (BY WEIGHT) VICTOR
FLASH POWDER (NORMAL GRADE) THIS MIXTURE (90% DRILLINGS · 10% FLASH POWDER)
SHOULD BE BROUGHT TO THE CONSISTENCY OF A HEAVY PASTE BY USE
OF A SOLVENT (ALCOHOL) AND TAMPED LIGHTLY INTO PLACE

FIG. 2.

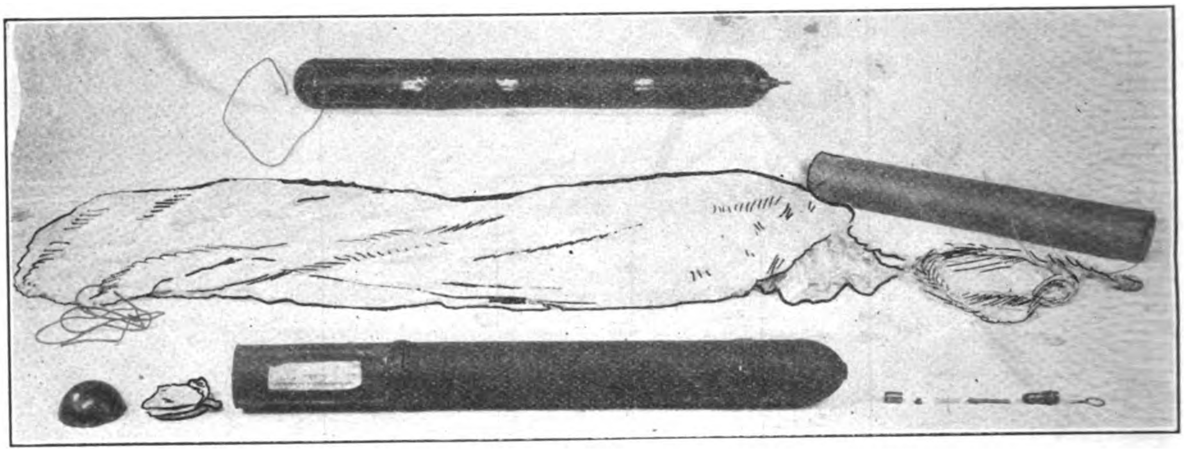


Fig. 3.—Modified Mark I parachute flare—composite.

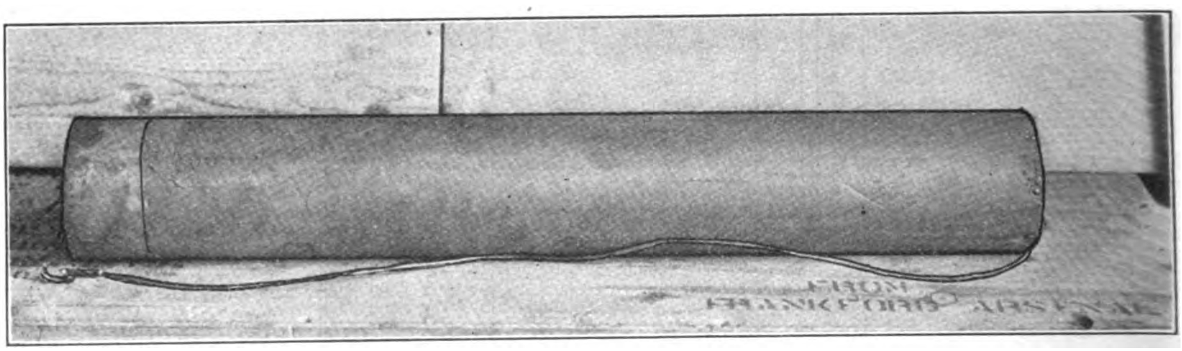


Fig. 4.—Mark I parachute flare (modified) candle.

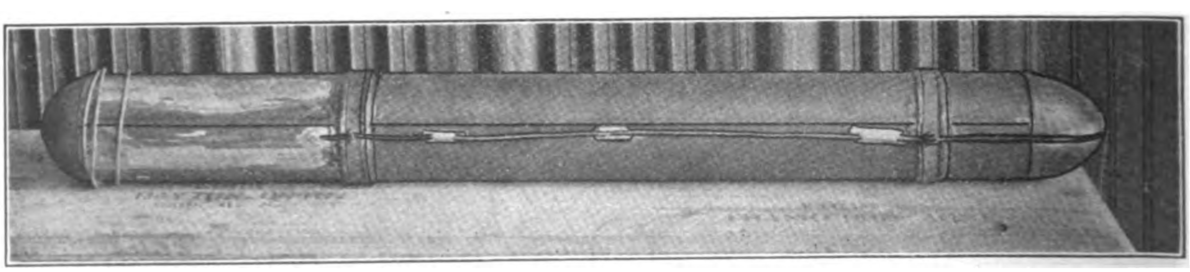


Fig. 5.—Mark I parachute flare (modified) bottom view.

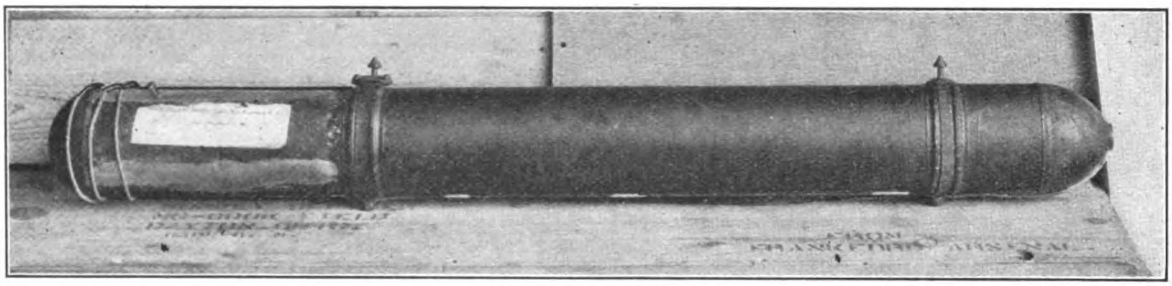


FIG. 6.—Mark I parachute flare (modified)—side view.

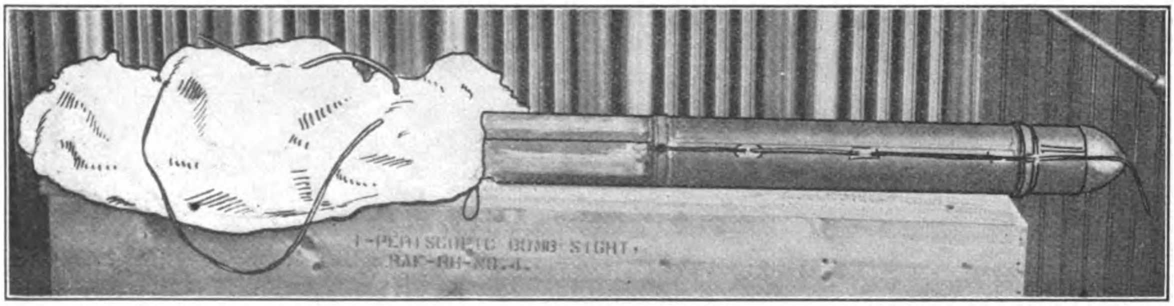


FIG. 7.—Mark I parachute flare (modified) disassembled.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV February 15, 1923 No. 393

PHYSICAL AND METALLOGRAPHIC PROPERTIES OF COPPER-ZINC-ALUMINUM ALLOYS CONTAINING SMALL AMOUNTS OF MAGNESIUM

(MATERIAL SECTION REPORT)

▽

Prepared by E. H. Dix, Jr., and Lieut. A. J. Lyon
Engineering Division, Air Service
McCook Field, Dayton, Ohio
July 10, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

PHYSICAL AND METALLOGRAPHIC PROPERTIES OF COPPER-ZINC-ALUMINUM ALLOYS CONTAINING SMALL AMOUNTS OF MAGNESIUM.

PURPOSE.

To determine the effect of replacing iron in aluminum alloy No. 3, Specification No. 11,019, by small amounts of magnesium.

CONCLUSIONS.

The use of magnesium in place of iron in aluminum alloy No. 3 is not advisable. An equal tensile strength in the "as cast" condition may be obtained with the addition of from 0.25 to 1 per cent magnesium in place of the iron, but the ductility, as measured by the percentage of elongation, is from 50 to 65 per cent lower. The hardness values are appreciably higher.

The best results were obtained with 0.5 per cent added magnesium, while with over 1 per cent, both the tensile strength and elongation fall off very rapidly.

A comparison of the effects of 0.5 per cent magnesium and 1 per cent of added iron on the average physical properties follows:

Composition.					Tensile strength (pounds per square inch).	Elongation in 2 inches (per cent)	Brinell hardness 500 kg./10 mm. ball.
Cu.	Zn.	Mg.	Fe.	Al.			
2.00	10.00	0.50	....	87.50	27,330	1.4	65.0
[1]2.00	10.00	....	1.00	87.00	[2] 28,140	8.8	52.4
					[3] 26,000	5.0	

[1] Composition used at McCook Field for aluminum alloy No. 3.
[2] McCook Field Report, Serial No. 1731.
[3] Routine average.

The tensile strength and hardness of the alloys in the magnesium-zinc series may be increased at the expense of the elongation by suitable heat treatment, but due to their low ductility and higher specific gravity they are inferior to the alloys of the duralumin type.

The following physical properties were obtained from aluminum alloy No. 3 with 0.5 per cent magnesium in place of iron:

Tensile strength, pounds per square inch.....	35,680.00
Elongation in 2 inches, per cent...............	0.83
Brinell......................................	80.00

The following metallographic constituents were observed in the alloys of this series:

A. Mg_2Si.
B. Al_2Mg_3–Al eutectic.
C. $CuAl_2$–Al eutectic.
D. Slate gray constituent, with purple tinge, which resembles constituent having the same color in the silicon-aluminum series. It is thought to be a compound of iron, silicon, and possibly of aluminum.
E. Needles of a similarly colored constituent considered $FeAl_3$.
F. In the furnace-cooled specimens a finely divided precipitate indentical in color to Al_3Mg_2.

MATERIAL.

The alloys used in this investigation were made in the material section foundry. The foundry melt numbers and chemical compositions of the raw materials used in their manufacture are as follows:

Material.	Melt No.	Chemical analysis.						
		Cu.	Si.	Fe.	Al.	Pb.	Cd.	Zn.
Aluminum ingot...	523	0.07	0.20	0.65	90.48	......	......	......
Zinc ingot..........	543	....	....	0.40	......	0.22	0.50	99.24
Magnesium........	919	Commercially pure stick.				......	......	......
Copper-aluminum hardener.........	1307	46.21	0.21	0.42	53.17	......	......	......

PROCEDURE.

The following alloys were made in melts of 30 pounds each:

Alloy symbol.	Melt No.	Composition as mixed.			
		Mg.	Cu.	Zn.	Al.
M-¼...............	1428	0.25	2.00	10.00	87.75
M-½...............	1434	.50	2.00	10.00	87.50
M-1...............	1438	1.00	2.00	10.00	87.00
M-2...............	1447	2.00	2.00	10.00	86.00
M-3...............	1453	3.00	2.00	10.00	85.00

The aluminum ingot and copper-aluminum hardener were charged together in a No. 30 plumbago crucible. The charge was melted in a gas-fired furnace. The maximum temperature was held between 1,300° and 1,350° F. The zinc was then introduced in the solid form and the pot drawn from the furnace, after which stick magnesium was introduced by holding beneath the surface of the molten metal until dissolved. No trouble was experienced from the magnesium igniting as long as the latter operation was performed quickly. The pouring temperature ranged from 1,270° to 1,300° F., the temperatures being recorded both in and out of the furnace with a chromel-alumel thermocouple (without protecting tube) in conjunction with a Hoskins high-resistance millivolt meter.

The following test specimens were poured in green sand from each melt:

Nine molds tension specimens (as cast), type TB-1.
Three porosity cups, type PC-2.
Three shrinkage bars.
One hot shortness test bar.

In addition to the above, 11 molds of tension specimens (as cast), type TB-1, were cast from each of the above melts from the gates and risers. The melt numbers corresponding to the different compositions are listed below:

Alloy symbol.	Melt No.
M-¼	1453
M-½	1436
M-1	1440
M-2	1449
M-3	1453

23908—23

EXPLORATORY MELTS.

The gates and risers were further used to make up the following exploratory melts. Four molds of tension specimens (as cast), type TB-1, were cast from each of these alloys:

Alloy symbol.	Melt No.	Composition as mixed.					
		Mg.	Cu.	Zn.	Al.	Si.	Te.
M-4½	1455	4.50	2.00	10.00	83.50	....	....
M.5-S.5	1472	.50	2.00	10.00	87.00	0.50	....
M2-S4	1456	2.00	2.00	10.00	82.00	4.00	....
M3-T2	1460	3.00	2.00	10.00	83.00	....	2.00

HEAT TREATMENT.

Tension specimens from the remelted and exploratory alloys were heat treated as follows:

Heat treatment symbol.	Number of bars.	Annealing temperature.	Quench.	Aging.
E	3	3 hours at 920° F.	Furnace cooled.	Room temperature.
F	3	.....do.	H_2O, 70° F.	Do.
G	3	.....do.	H_2O, 212° F.	3 hours at 212° F.

Test bars in the "as cast" condition were set aside to age one month, six months, one year, two years, three years, and four years.

PHYSICAL TESTS.

The standard practice was observed in making tension tests and hardness and specific gravity determinations. Six bars from each of the original melts and three bars from the remelts and exploratory melts were pulled within 48 hours after casting. Heat treated and aged specimens were pulled "as cast." Three bars from each of the original melts were machined in order to determine the "skin effect." Test bars from melts 1428, 1434, and 1438 were threaded and pulled in self-aligning adapters at 200°, 400°, and 600° F.

SHRINKAGE AND HOT SHORTNESS TESTS.

The method of making the shrinkage determinations and hot shortness test is outlined in Material Section Report No. 178, Serial No. 1964, A. S. Information Circular Vol. IV, No. 385.

POROSITY TEST.

The method of making this test is described in Material Section Report No. 160, Serial No. 1882.

CHEMICAL ANALYSES.

The original melts were analyzed for copper, iron, zinc, and silicon, and the aluminum taken as the difference.

METALLOGRAPHIC.

Metallographic specimens were taken from the riser end of the middle test bar in all cases. Specimens of the original melts, remelts, and heat-treated material were examined.

RESULTS.

The results of the tension tests, hardness and specific gravity determinations, and shrinkage tests are summarized in Table 1 and shown graphically in Figures 1, 2, and 3.

The results of the tests at elevated temperatures are shown in Figures 4 and 5.

The alloys of this series give somewhat erratic porosity results, ranging from 81 sec. per 1,000 cubic centimeters to 2,600 sec. per 1,000 cubic centimeters. The results were in no way consistent with the different compositions, but taking the alloys in the useful range, the results are considerably below those obtained in the iron-copper-zinc series.

CHEMICAL ANALYSES.

The results of chemical analyses are shown in Table 2.

METALLOGRAPHIC EXAMINATION.

The average structure and the characteristic appearance of the constituents observed in this series are shown in Plate 1 and are discussed under the heading, "Discussion of results."

AGING TESTS.

The results of the one month aging test are included in Table 1. The remainder of the specimens are on file in the metals branch, to be pulled at later dates.

DISCUSSION OF RESULTS.

Figure 1 indicates that the useful range of magnesium in the copper-zinc-aluminum alloys is limited to 0.25 to 1 per cent. (Alloys containing more than 1 per cent magnesium were too brittle to obtain reliable or consistent tension test results.)

Figure 2 shows that the highest elongation of the alloys investigated is less than 2 per cent, which is very low when compared to the alloys containing iron in place of magnesium. In the former alloys an elongation of 5 per cent is regularly obtained in routine practice, while as high as 8 per cent was obtained in the experimental melts. Even though the tensile strength is about the same, this lack of ductility precludes the use of magnesium in place of iron in aluminum alloy No. 3, Specification No. 11019. By heat treatment the tensile strength of the alloys containing magnesium in the limits specified above may be considerably increased. The elongation is either not affected or slightly decreased.

The hardness values of the magnesium series in both the "as cast" and heat treated conditions are considerably above those obtained for the iron alloy.

The high temperature tests show that magnesium does not increase the usefulness of the alloy under Specification No. 11019 for parts subjected to high temperatures.

The hot shortness and shrinkage results are on the same order as those obtained for aluminum alloy No. 3.

EXPLORATORY MELTS.

The exploratory melts are not of special interest. The addition of silicon to alloys containing more than 1 per cent magnesium slightly increases the tensile strength and malleability. Tellurium has practically no effect on the physical properties when added to a 3 per cent magnesium alloy of this series.

Magnesium first appears as a blue constituent, which is shown in Plate 1, Figures 1 and 2. This corresponds to the constituent which has been identified by British workers (Ref. Eleventh Report of the Alloy Research Committee) as Mg_2Si. In the alloys containing less than 1 per cent of magnesium it occurs in very small globules.

With more than 1 per cent of magnesium, the globules increase in size and in quantity and often have a mottled appearance with black edges. It was also observed that this constituent occurs intimately mixed with the $CuAl_2$ and suggests a ternary eutectic. Hanson and Gayler (Ref. Institute of Metals (British), Vol. XXVI, pp. 321–359, inclusive) have attributed the aging effect of duralumin to this constituent. In the copper-zinc-magnesium aluminum alloys, no difference either in the amount or the form of the Mg_2Si was observed in the "as cast" and heat treated conditions. Some of the copper and all of the zinc enter into solid solution with the aluminum and undoubtedly affect the solubility of the magnesium compounds and may alter the limits given by Hanson. It was found that the $CuAl_2$, visible in the "as cast" specimens, readily goes into solution when subjected to the heat treatments.

Between 1 and 2 per cent added magnesium, a constituent corresponding to Al_2Mg_3, as described by Hanson (Institute of Metals (British), Vol. XX, p. 201), makes its appearance. This constituent is shown in Plate 1, Figure 4. It is readily attacked by dilute solutions of nitric acid of either alcohol or water. In the unetched specimen it is only faintly visible, but is colored black by a 10 per cent solution of nitric acid in alcohol. The appearance of this constituent corresponds to the maximums on the tensile strength and elongation curves in Figures 1 and 2.

In the furnace-cooled specimens containing over 1 per cent magnesium a precipitate of globules and needles which were too faint to be resolved at 500 diameters was observed throughout the matrix. At 1,000 diameters, however, these particles appeared similar to the larger areas of Al_2Mg_3 and reacted in the same manner when etched with 10 per cent alcoholic nitric acid solution. In this respect it is interesting to note that the hardness values of these furnace-cooled alloys rapidly decrease with an increase in the magnesium content, while with the alloys in the cast condition, heat treated, and quenched, show an increase in hardness.

A slate gray constituent with a purple tinge was observed throughout this series, the amount of which was neither affected by the magnesium content nor the various heat treatments. This resembles what is thought to be the iron-silicon compound which has been observed in practically all of the alloys of aluminum and is described in Material Section Report No. 178, Serial No. 1964, Air Service Information Circular, Vol. IV, No. 385. It is shown in the half-tone areas of Figures 1 and 2, Plate 1. Figure 3 shows needles of a similarly colored constituent whose shape indicates $FeAl_3$, which is also described in the report just mentioned. These needles were observed principally in the exploratory melts containing added silicon.

TABLE 1.

Alloy symbol.	Number of bars.	(1)	Tensile strength (pounds per square inch).	Elongation in 2 inches, (per cent).	Brinell.	Rockwell.	Scleroscope.	Specific gravity.	Shrinkage (inches per foot).
M-¼	6	A	24,960	1.40	60	52	16	2.87	0.1087
	3	B	26,140	2.00	57	53	19	......	
	3	C	23,760	1.17	70	52	23	2.86	
	3	D	29,700	1.5	70	55	29	2.85	
	3	E	27,660	1.17	77	61	27	2.87	
	3	F	35,800	1.5	83	65	33	2.88	
	3	G	34,220	2.0	80	63	28	2.86	
M-½	6	A	27,330	1.40	65	50	19	2.87	0.1049
	3	B	26,390	1.80	63	54	17	2.86	
	3	C	25,310	1.00	70	53	18	2.85	
	3	D	28,440	1.50	67	57	25	2.85	
	3	E	31,120	1.00	74	60	28	2.87	
	3	F	31,670	1.17	77	62	29	2.86	
	3	G	35,680	.83	80	62	31	2.86	
M-1	6	A	21,935	1.35	72	56	19	2.85	0.0975
	3	......	22,160	.83	77	65	30	2.85	
	3	C	20,910	1.0	74	61	21	2.84	
	3	D	23,860	1.5	74	64	27	2.82	
	3	E	21,390	.67	63	54	22	......	
	3	F	22,160	.83	77	65	30	2.85	
	3	G	35,590	.67	86	68	35	......	
M-2	6	A	11,415	.50	83	61	21	2.84	0.0833
	3	B	16,590	.50	80	61	20	2.86	
	3	D	13,520	1.0	96	67	35	2.83	
	3	E	11,630	.67	48	34	13	2.80	
	2	F	12,130	.50	91	67	37	2.83	
	3	G	15,330	.5	100	74	45	2.80	
M-3	3	A	10,890	.5	93	63	26	2.82	0.0831
	......	B	8,790	.3	93	66	26	2.76	
	......	C	12,380	.5	93	70	40	2.84	
	......	E	5,950	.5	38	23	11	2.66	
	......	G	1,050	......	119	77	54	2.79	
M-4½	3	A	8,790	.3	93	66	26	2.76	
	3	G	4,500	......	100	73	54	2.67	
M2-S4	3	A	21,150	.5	86	62	19	2.80	
	3	E	19,950	1.0	86	48	31	2.78	
	3	G	28,400	.5	93	68	36	2.83	
M.5-S.5	3	A	25,475	.5	73	54	18	2.81	
	3	E	28,200	1.0	73	59	24	2.87	
	3	F	33,120	.83	86	65	34	2.85	
	3	G	33,540	.83	80	64	31	2.86	
M3-T2	......	A	15,250	.50	86	61	22	2.85	
	3	......	9,400	.67	96	68	35	2.86	

[1] A. "As cast" condition.
B. "As cast." Remelt of A.
C. Same as A. Machined.
D. Same as B. Aged one month.
E. Three hours at 920°F. Furnace cooled.
F. Three hours at 920°F. H_2O, 70°F.
G. Three hours at 920°F. Quench, H_2O, 212°F. Aged three hours at 212°F.

TABLE 2.

Alloy symbols.	Melt No.	Composition as mixed.						Chemical analysis.[1]					
		Mg.	Cu.	Zn.	Al.	Si.	Te.	Mg.	Cu.	Zn.	Fe.	Si.	Al.
M-¼	1428	0.25	2.00	10.00	87.75	....	....	0.53	2.10	10.58	0.47	0.31	86.01
M-½	1434	.50	2.00	10.00	87.50	....	....	.59	2.06	10.18	.46	.30	86.41
M-1	1438	1.00	2.00	10.00	87.00	....	....	1.03	1.95	9.96	.60	.30	86.16
M-2	1447	2.00	2.00	10.00	86.00	....	....	1.65	2.06	9.67	.44	.23	85.95
M-3	1453	3.00	2.00	10.00	85.00	....	....	1.70	2.18	9.46	.44	.23	85.99
M-4½	1455	4.50	2.00	10.00	83.50	....	....	....	....	....	....	....	....
M2-S4	1456	2.00	2.00	10.00	82.00	4.00	....	....	....	....	....	....	....
M.5-S.5	1472	.50	2.00	10.00	87.00	.50	....	....	....	....	....	....	....
M3-T2	1460	3.00	2.00	10.00	83.00	....	2.00	....	....	....	....	....	....

[1] Not determined for melt Nos. 1455, 1456, 1472, and 1460.

ADDENDUM.

PHYSICAL PROPERTIES AFTER SIX MONTHS' AGING.

Melt No.	1433	1433	1433	Average.	1436	1436	1436	Average.
Chemical composition	Cu 2; Zn 10; Mg .25; Al. bal.				Cu 2; Zn 10; Mg .5; Al. bal.			
Specimen No.	4-A	4-B	4-C		6-A	6-B	6-C	
Type of specimen	Cast round.				Cast round.			
Diameter, inches	0.502	0.504	0.494		0.493	0.502	0.500	
Ultimate strength (pounds per square inch)	27,740	21,800	23,900	24,480	27,760	31,430	30,200	29.800
Elongation, per cent in 2 inches	0.5	0.5	0.5	0.5	0.5	1.0	1.0	0,83
Location of fracture	O T	O T	O T		O T	O T	O T	O
Character of fracture	Coarse-granular.				Coarse-granular.			

Melt No.	1440	1440	1440	Average.	1449	1449	1449	Average.
Chemical composition	Cu 2; Zn 10; Mg 1.0; Al. bal.				Cu 2; Zn 10; Mg 2.0; Al. bal.			
Specimen No.	6-A	6-B	6-C		6-A	6-B		
Type of specimen	Cast round.				Cast round.			
Diameter, inches	0.503	0.502	0.493		0.502	0.503	....	
Ultimate strength (pounds per square inch)	21,250	21,320	25,620	22,730	13,290	16,560	....	14,925
Elongation, per cent in 2 inches	1.0	1.0	0.5	0.83	....	....	....	
Location of fracture	O T	M T	O T	....	O T	O T	....	
Character of fracture	Coarse-granular.				Coarse-granular.			

Melt No.	1457	1457	1457	Average.
Chemical composition	Cu 2; Zn. 10; Mg. 3; Al. balance.			
Specimen No.	10–A	10–B	10–C	
Type of specimen	Cast round.			
Diameter, inches	0.496	0.508	0.503	
Ultimate strength (pounds per square inch)	14,490	7,840	10,520	10,950
Elongation, per cent in 2 inches	0.50	0 50	0.50	0.50
Location of fracture	O T	M T	O T	
Character of fracture	Coarse-granular.			

Fig. 1. 1000 X. Unetched.
Black - Mg_2Si
Light - $CuAl_2$
Half tone - probably X constituent.

Fig. 2. 1000 X. Etch 10 per cent Solution HNO_3 in Alcohol
Black - Al_2Mg_3
Half tone - probably X constituent.

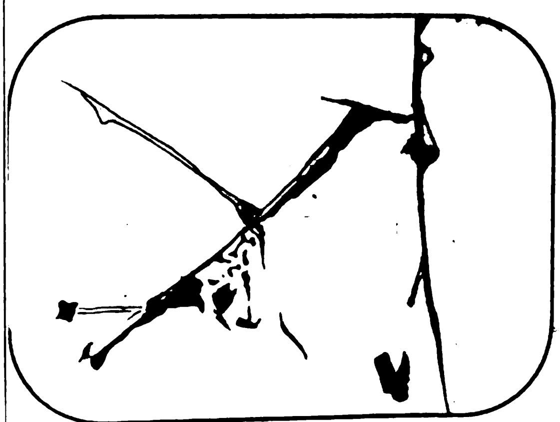


Fig. 3. 1000 X. Unetched.
Black - Mg_2Si
Light - $CuAl_2$
Half tone - probably needles $FeAl_3$.

Fig. 4 - 1000 X. Etch 10 per cent Solution HNO_3 in Alcohol
Precipitate in furnace-cooled specimens (Black) which resembled Al_2Mg_3.

Plate 1.

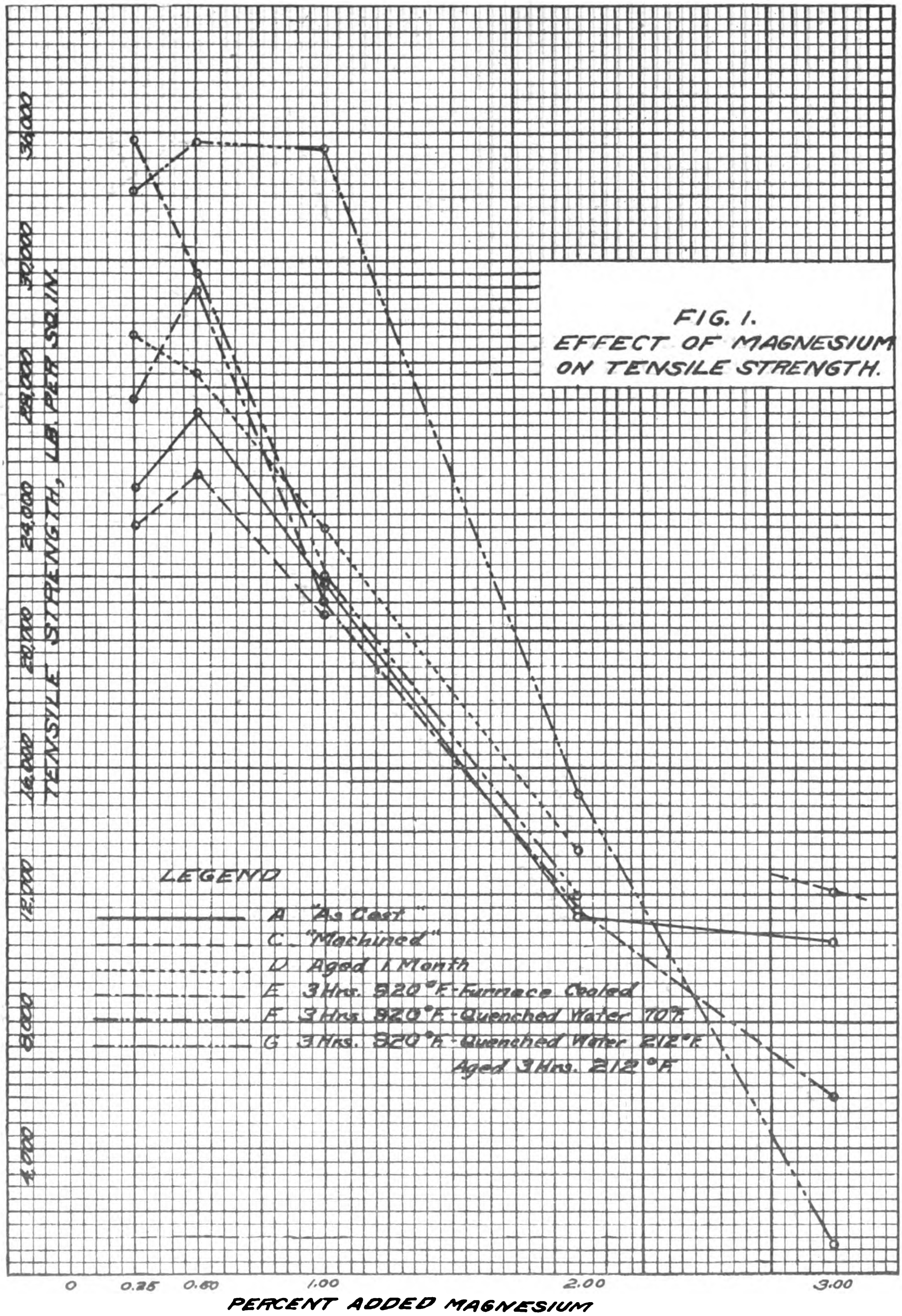


FIG. 1.
EFFECT OF MAGNESIUM
ON TENSILE STRENGTH.

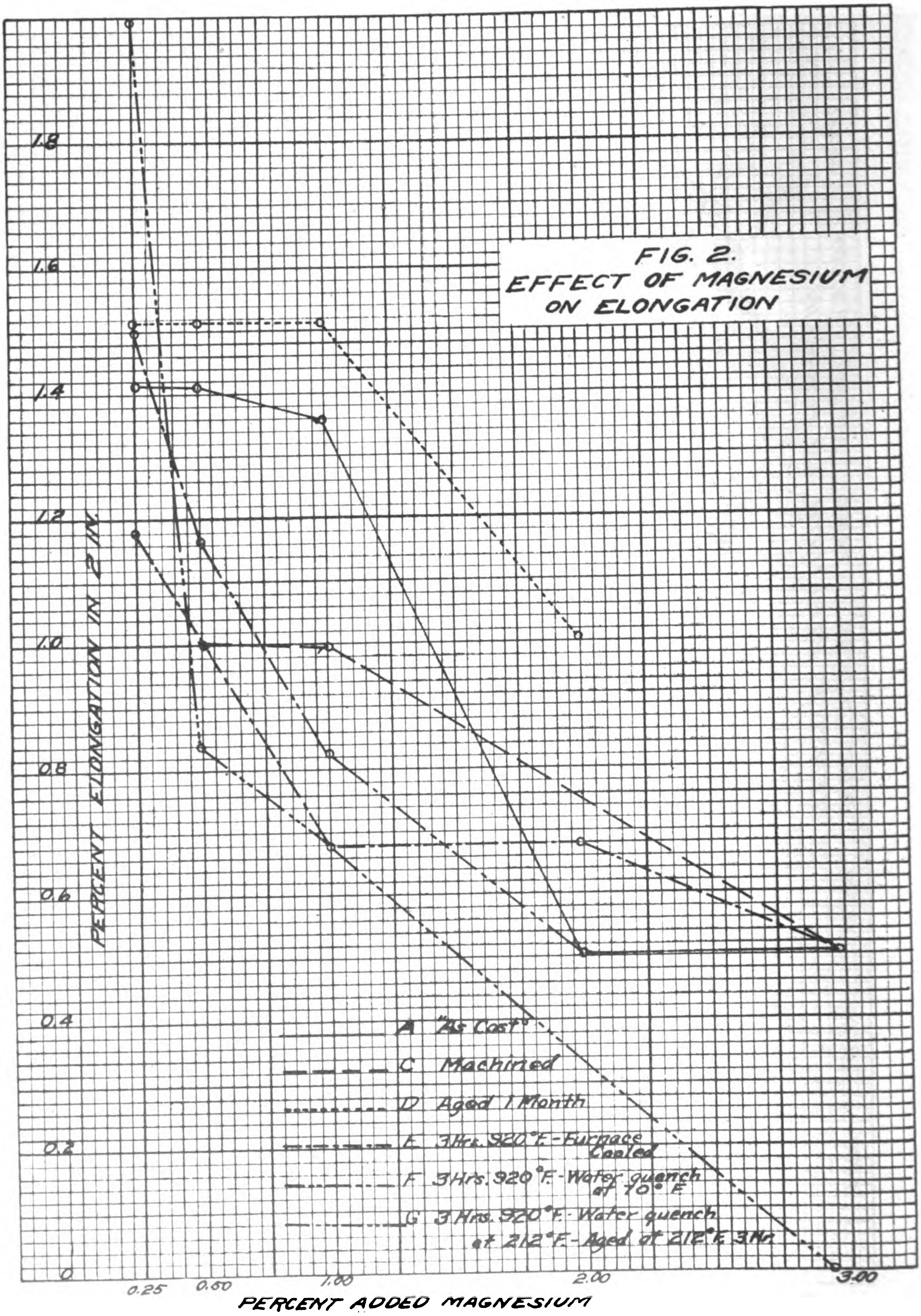
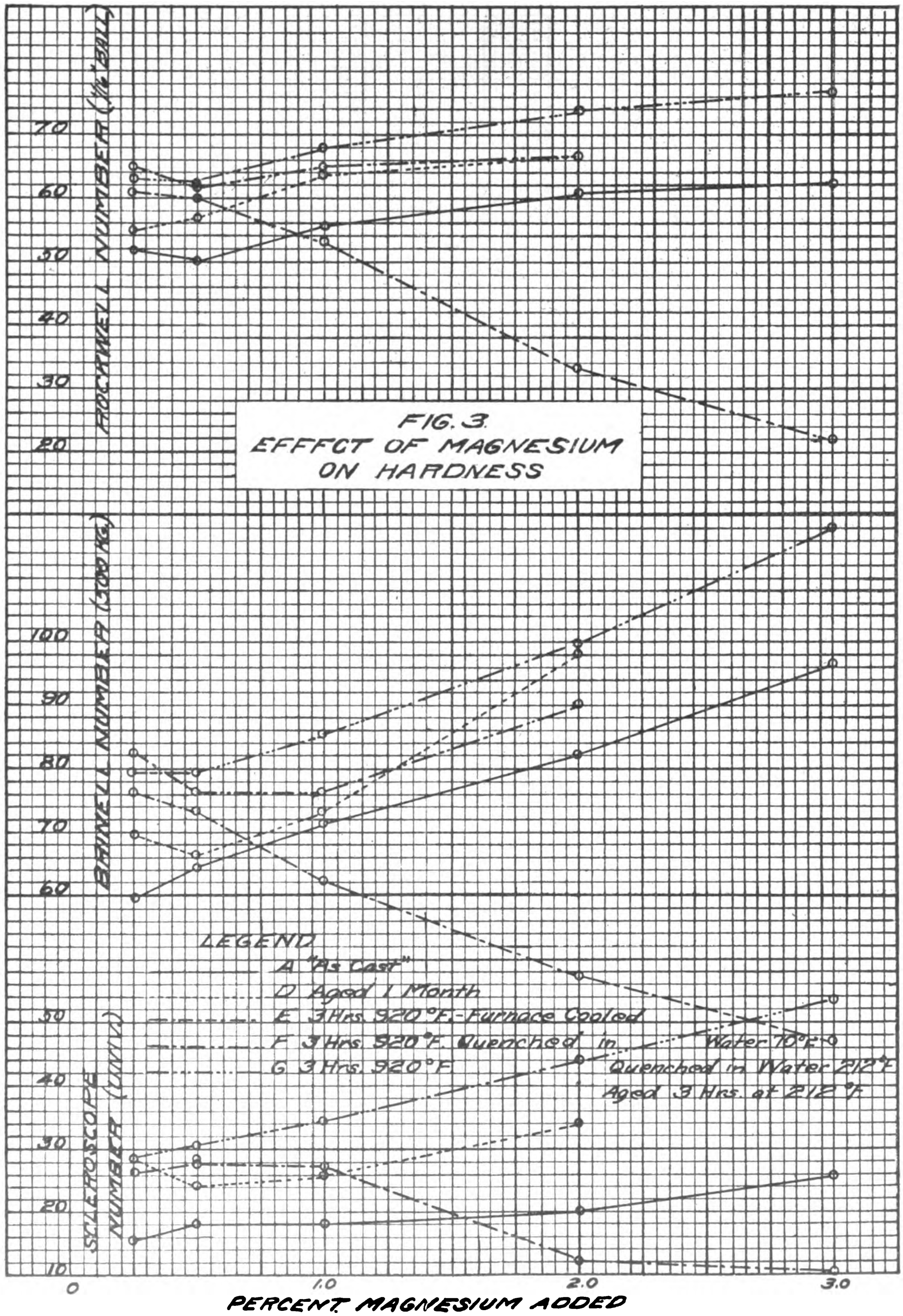


FIG. 2.
EFFECT OF MAGNESIUM ON ELONGATION


ROCKWELL NUMBER (1/16" BALL)
BRINELL NUMBER (500 Kg.)
SCLEROSCOPE NUMBER (UNIV.)
70
60
50
40
30
20
100
90
80
70
60
50
40
30
20
10
0
1.0
2.0
3.0
PERCENT MAGNESIUM ADDED
FIG. 3
EFFECT OF MAGNESIUM ON HARDNESS
LEGEND
A "As Cast"
D Aged 1 Month
E 3 Hrs. 920°F. Furnace Cooled
F 3 Hrs. 920°F. Quenched in Water 70°F
G 3 Hrs. 920°F Quenched in Water 212°F Aged 3 Hrs. at 212°F

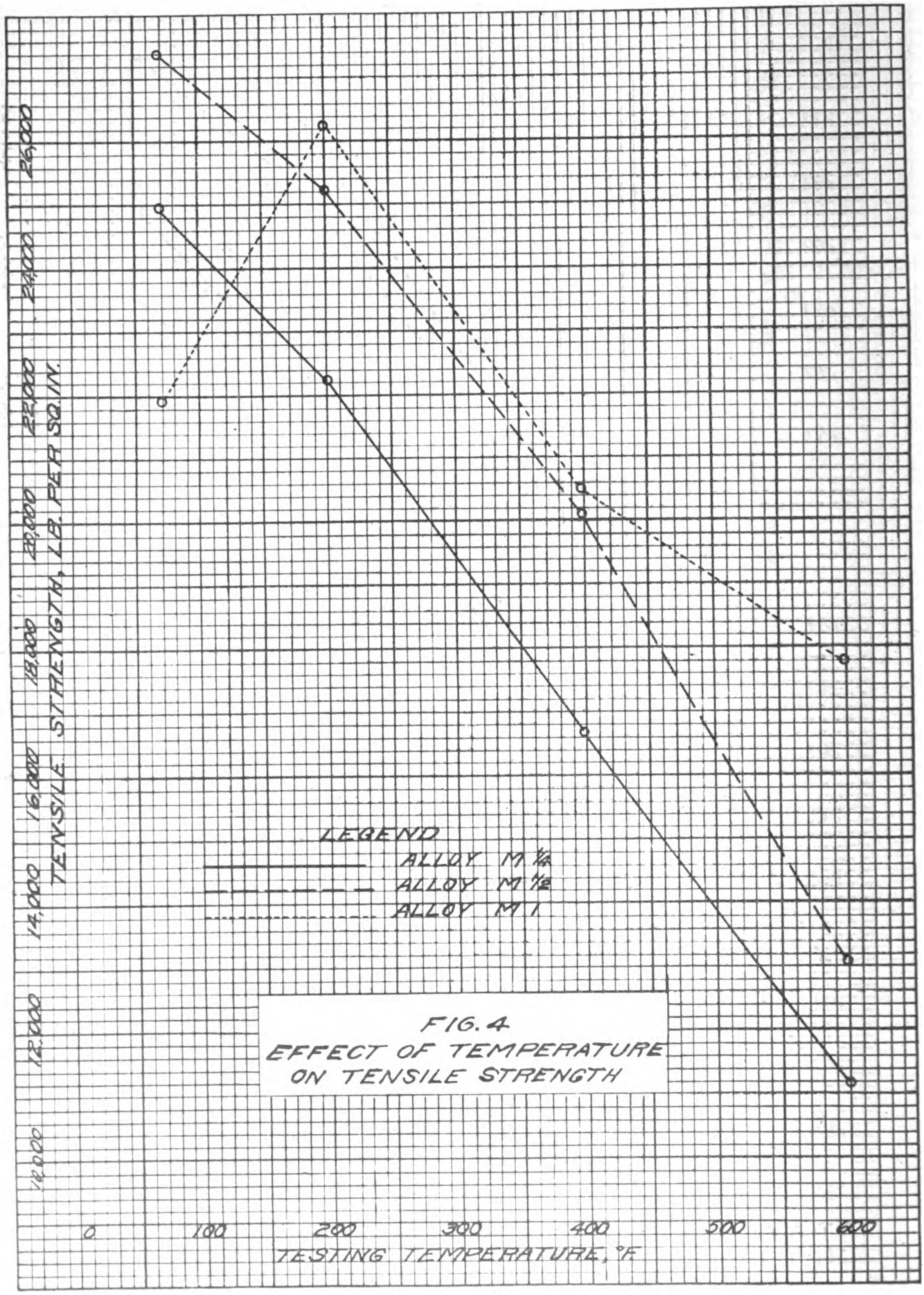


FIG. 4
EFFECT OF TEMPERATURE
ON TENSILE STRENGTH

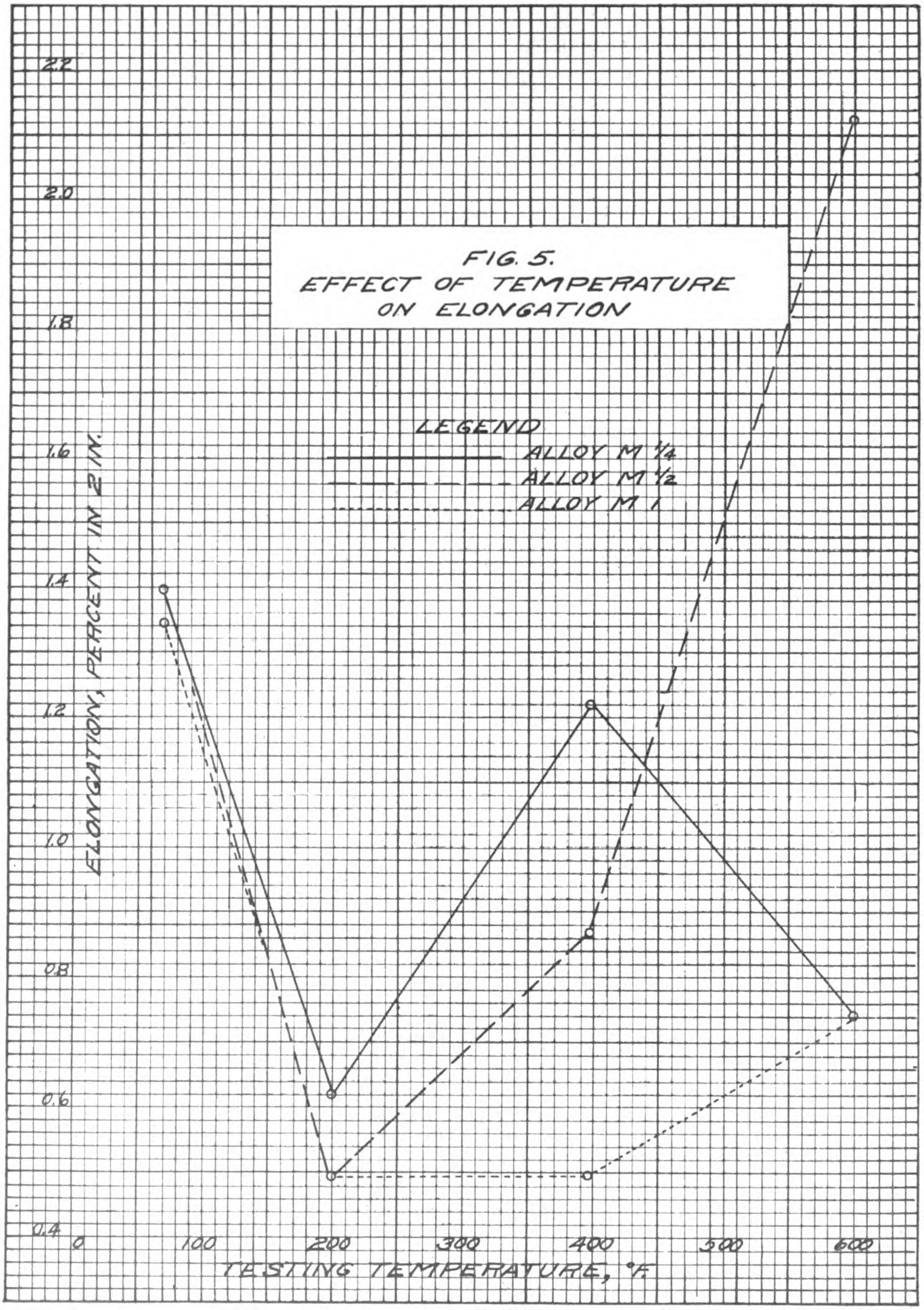


FIG. 5.
EFFECT OF TEMPERATURE
ON ELONGATION
LEGEND
ALLOY M 1/4
ALLOY M 1/2
ALLOY M 1
ELONGATION, PERCENT IN 2 IN.
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0
100
200
300
400
500
600
TESTING TEMPERATURE, °F.

O

File D 52331/40 McCOOK FIELD REPORT, SERIAL No. 2008

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV February 15, 1923 No. 394

THE DISTRIBUTION OF LOAD AMONG THE SPARS IN MULTI-SPAR CONSTRUCTION OF AIRPLANE WINGS

(AIRPLANE SECTION REPORT)

▽

Prepared by J. S. Newell
Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 16, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

THE DISTRIBUTION OF LOAD AMONG THE SPARS IN MULTI-SPAR CONSTRUCTION OF AIRPLANE WINGS.

PURPOSE AND SCOPE OF REPORT.

With the development of large internally braced airplane wings, the simple two-spar type of construction appears to be uneconomical as regards material and weight. Accordingly three or more spars are sometimes employed, and with the introduction of this multispar construction comes the question as to the manner in which the load on the wing is distributed among the spars. The following report covers an investigation of a number of methods of apportioning the load as applied to a large three-spar metal wing, a study of the results obtained as compared with the distribution indicated by the sand test of this wing, and the conclusions based upon that study.

Owing to scarcity of data concerning the distribution of the wing load among three or more spars, it is impossible to offer a formula that is entirely satisfactory for use in design since proof of its applicability is lacking. This investigation, being limited to one specific case, has been carried out to eliminate such methods as show themselves to be inapplicable and to establish a basis for future research for the purpose of obtaining a satisfactory method of apportioning the wing loads among the spars.

The methods considered and the results obtained are discussed in detail in the following pages. The data on which the investigation depends are given in Tables 1 to 8, inclusive, which show the distribution of the sand load, the moments of inertia of the spars at the different panel points, and the deflections of the wing obtained during the sand test. Figure 1 gives the general dimensions of the wing, the location of the spars, and the scheme of lettering the panel points of the trussed spars.

TABLE 1.—*Moments of inertia.*

	Root	M	N	O	P	Q	R
Front spar	408	235	148	86	42	27	13
	Root	G	H	I	J	K	L
Center spar	421	323	200	117	70	49	22
	Root	A	B	C	D	E	F
Rear spar	255	195	121	72	41	28	10

TABLE 2.—*Distribution of sand load over a cross section.*

	Low incidence—Center of pressure at 50 per cent.			High incidence—Center of pressure at 33 per cent.		
Per cent of chord from leading edge	0-32	32-64	64-90	0-26.5	26.5-46.5	46.5-91.5
Per cent of sand load in section	30	30	40	50	25	25

TABLE 3.—*Low incidence.*

Factor.	Rear spar deflections in inches.							Retreat.
	A	B	C	D	E	F	S	Z
1.5	0.9	1.9	3.0	4.0	4.9	5.8	7.0	−0.4
2	1.3	2.4	4.3	5.7	7.7	8.5	10.1	−.7
2.5	1.6	3.3	5.4	7.9	10.0	11.3	12.5	−1.0

TABLE 4.

Factor.	Center spar deflections in inches.						
	G	H	I	J	K	L	T
1.5	0.7	1.4	2.1	3.1	4.0	5.1	5.9
2	1.1	2.0	3.3	4.4	5.7	6.8	8.1
2.5	1.2	2.3	3.8	5.8	7.4	8.8	10.4

TABLE 5.

Factor.	Front spar deflections in inches.						
	M	N	O	P	Q	R	U
1.5	0.4	1.0	1.4	2.3	3.2	3.7	4.6
2	.6	1.3	2.0	3.2	4.3	5.1	6.1
2.5	1.0	1.6	2.5	3.9	5.6	6.5	7.9

TABLE 6.—*High incidence.*

Load factor.	Rear spar deflections in inches.							Retreat
	A	B	C	D	E	F	S	Z
3	1.2	2.1	3.7	5.6	7.2	8.7	10.2	+1.6
3.5	1.4	2.7	4.4	6.5	8.7	10.5	12.3	+2.3
3.75	1.6	2.9	4.8	7.2	9.5	11.4	13.4	+2.4

TABLE 7.

Factor.	Center spar deflections in inches.						
	G	H	I	J	K	L	T
3	1.5	2.7	4.4	6.4	8.2	9.8	11.5
3.5	1.6	3.2	5.2	7.5	9.8	11.7	13.6
3.75	1.8	3.4	5.6	8.2	10.5	12.6	14.7

TABLE 8.

Factor.	Front spar deflections in inches.						
	M	N	O	P	Q	R	U
3	1.4	3.0	4.8	6.8	9.0	10.5	12.0
3.5	1.8	3.5	5.5	8.1	10.5	12.6	14.1
3.75	2.0	3.9	6.1	8.8	11.5	13.4	15.6

DISTRIBUTION OF STRESS DETERMINED FROM SAND TEST DATA.

In a solid spar of constant cross section the deflection may be expressed in the general form $\Delta=\frac{C\,w\,L^3}{EI}$ when C is a constant dependent upon the distribution of the load and the method of support. While this formula probably does not hold exactly for a trussed spar or one of varying cross section, the error introduced by considering C to be a constant for spars of the same type, but different depths, under similar loading conditions would be small. In the wing under consideration the lengths of the three spars are, for all practical purposes, the same and the modulus of elasticity is a constant. By rearranging the above formula we get $w=kI\Delta$, where $k=\frac{E}{CL^3}$.

The loads causing a given set of deflections may therefore be computed. Owing to the difficulty of obtaining values of k for the spars of a wing such as this, and for the purpose of simplifying the numerical work, the computations will be made on the basis of a percentage distribution of the load among the spars. To establish a satisfactory basis for comparing the results of various formulæ all computations will be made for distribution of the load at the third panel point from the root, the distribution as calculated from the deflection data being taken as the standard for comparison.

It is to be noted that the deflection at the third panel point is a function not only of the loads and moments of inertia at that panel point but also of those at the panel points between that and the root. Having the moments of inertia and deflections for each panel point of each spar we shall compute the load on each spar that would cause a cantilever beam having a constant moment of inertia equal to the mean of the moments of inertia of the panel points between the root and the third panel point to deflect a distance equal to the mean deflection of these same panel points. The deflections and moments of inertia are assumed to have straight line variations between panel points.

LOW INCIDENCE.

FRONT SPAR.

Mean deflection $=1/8(\delta_r+3\delta_1+3\delta_2+\delta_3)=1/8(0.0+1.2+3.0+1.4)=0.7$ in.

Mean $I=1/8(I_r+3I_1+3I_2+I_3)=1/8(408+762+442+86)=212.5$ in.[4]

$$\frac{W_F}{k}=I_F\delta_F=212.5\times0.7=148.7$$

CENTER SPAR.

Mean $\delta=1/8(0.0+2.1+4.2+2.1)=1.05$ in.

Mean $I=1/8(420.5+969+600+117)=263.3$ in.[4]

$$\frac{W_C}{k}=I_C\delta_C=263.3\times1.05=276.$$

REAR SPAR.

Mean $\delta=1/8(0.0+2.7+5.7+3.0)=1.45$ in.

Mean $I=1/8(254+585+363+72)=159$ in.[4]

$$\frac{W_R}{k}=I_r\delta_R=159\times1.45=231.$$

	Per cent.
Front spar carries	$\frac{149}{656}=22.6$
Center spar carries	$\frac{276}{656}=42.1$
Rear spar carries	$\frac{231}{656}=35.2$

The above computations are for the third panel point under a low incidence load factor of 1.5. Similar computations were made for load factors of 2 and 2.5, the averages of the three results being

	Per cent.
Front spar	22.9
Center spar	42.8
Rear spar	34.3

Following the same methods the average distribution of the load at the third panel point for the three factors of the high incidence load was found to be

	Per cent.
Front spar	36.9
Center spar	41.8
Rear spar	21.3

The agreement of the loads carried by each spar under each load factor with the average values given above for the three load factors was very close, so the actual values will not be given here.

Similar computations were made for one panel, and for two panels each based on the deflection data for the three load factors in low and in high incidence. The following percentages are in each case averages of the values for the three load factors, the variation from these averages being a matter of 1 or 2 per cent for any load factor.

LOW INCIDENCE.

Member.	1 panel.	2 panels.	3 panels.	Averages for 1, 2, and 3 panel.
	Per cent.	Per cent.	Per cent.	Per cent.
Front spar	24.5	23.9	22.9	23.8
Center spar	42.8	42.7	42.8	42.8
Rear spar	32.7	33.4	34.3	33.4

HIGH INCIDENCE.

Member.	1 panel.	2 panels.	3 panels.	Averages for 1, 2, and 3 panel.
Front spar	38.2	37.7	36.9	37.6
Center spar	40.8	41.4	41.8	41.3
Rear spar	21.0	20.9	21.3	21.1

It will be seen from the above that the distribution of load existing at the third panel point is in close agreement with the average values for the first, second, and third panels.

The above values indicate the manner of distribution among the three spars of the load on the wing as computed from the deflection data obtained during the sand test.

Various other methods for calculating this distribution for use in design will now be investigated and the results compared with those given above.

DISTRIBUTION IN PROPORTION TO MOMENTS OF INERTIA.

The first method to be considered assumes that the load carried by each spar is in proportion to the moment of inertia of the spar.

From Table 1 at the third panel point.

	Moment of inertia.	Load.
Front spar	86	$\frac{86}{275}=31.3\%$
Center spar	117	$\frac{117}{275}=42.5\%$
Rear spar	72	$\frac{72}{275}=26.2\%$
	275	

This assumption is obviously of little value since it makes no provision for a different distribution under a high from that under a low incidence loading. By comparing the percentages as given by this method with those obtained from the deflections, it will be seen that this distribution would give unsafe design loads for the front and rear spars, though satisfactorily providing for the center spar in this case.

DISTRIBUTION IN PROPORTION TO LOAD ON AREA ASSUMED TO BE CARRIED BY EACH SPAR.

A second assumption is that each spar carries that portion of the load lying between the mid-points of the spans to either side of the spar. In Figures 2 and 3 the chord is taken as 100 units in length and the load expressed in pounds per per cent of chord. The shaded areas indicate the portions carried by the front and rear spars; the clear area that carried by the center spar. For distribution of load over the cross-section, see Table 2.

LOW INCIDENCE LOADING.

	Per cent.
Front spar, 0.937×27.5	$=25.8$
Center spar, 0.937×25	$=23.0$
Rear spar, $0.937\times11.5+1.54\times26$	$=50.8$

HIGH INCIDENCE LOADING.

	Per cent.
Front spar, $1.885\times26.5+1.25\times1$	$=51.3$
Center spar, $1.25\times19+0.555\times6$	$=27.1$
Rear spar, 0.555×39	$=21.6$

This method is of very little value, as it indicates a very light loading on the center spar which, as determined by the deflections, carries about 40 per cent of the load in both low and high incidence.

DISTRIBUTION IN PROPORTION TO SPAR AREAS BY THE USE OF IMAGINARY SPARS.

A distribution that approximates the conditions encountered in a three-spar wing is obtained by substituting one imaginary spar of area equal to the combined area of the front and center spars acting at the center of gravity of the areas of these spars, and another similar spar of area equal to that of the center and rear spars acting at their center of gravity, computing the load in each of these imaginary spars and then dividing it between the actual spars, of which the imaginaries are made, in proportion to their respective areas.

LOW INCIDENCE LOADING.

Imaginary spar 1, $\frac{0.467\times25}{0.638\times0.467}=10.6$ (location of C. G. from front spar).

Imaginary spar 2, $\frac{0.516\times25}{0.467\times0.516}=13.1$ (location of C. G. from center spar).

Spar 1 carries $\frac{3.1\times W}{27.5}=0.113W$

Spar 2, $\frac{24.4W}{27.5}=0.887W$

Front spar $=\frac{0.638}{1.105}\times0.113=6.5$ per cent.

Center spar $=\frac{0.467\times0.113}{1.105}+\frac{0.467\times0.887}{0.983}=47$ per cent.

Rear spar $=\frac{0.516}{0.983}\times0.887=46.5$ per cent.

HIGH INCIDENCE LOADING.

Imaginary spar 1 carries $\frac{20.1W}{27.5}=0.731W$

Imaginary spar 2 carries $\frac{7.4W}{27.5}=0.269W$

Front spar carries $\frac{0.638}{1.105}\times0.731=42.2$ per cent.

Center spar carries $\frac{0.467}{1.105}\times0.731+\frac{0.467\times0.269}{0.983}=43.7$ per cent.

Rear spar carries $\frac{0.516}{0.983}\times0.269=14.1$ per cent.

The above method of substituting imaginary spars gives a conservative distribution of stresses for use in design. In this case, for a three-spar wing, the results would be quite satisfactory for purposes of design, but it is apparent that the computations inherent in the extension of this scheme to a multi-spar wing would be somewhat involved.

THE BURGESS RATIONAL METHOD.

The next solution of the problem to be considered is a rational, theoretical method, the development of which is due to Mr. C. P. Burgess, of the Bureau of Aeronautics of the Navy Department, and, with one or two minor changes in signs and nomenclature, is as follows.

Figure 6 shows the cross section of an internally braced multi-spar wing having n spars numbered from 1 to n proceeding from the leading toward the trailing edge.

Curve *A* represents the distribution of the air force normal to the wing as a compound of the pressures on the upper and lower surfaces.

F is the resultant air force per unit length of the wing minus the weight of the wing per unit of length. It is assumed that F acts at the center of pressure on the cross section. The moment of F about the leading edge will be represented by M.

23909—23——2

$W_1, W_2, W_3, \ldots W_n$ are the loads per unit length along spars $1, 2, \ldots n$ at the section under consideration.

$I_1, I_2, \ldots I_n$ are the moments of inertia of the respective spars about their neutral axes, $d_1, d_2, \ldots d_n$ being the distances of the spars from the leading edge.

If the wing root be assumed to be fixed in position the air load will cause the wing to bend so that any cross section will rise a vertical distance, v, and rotate through a small angle, θ, the assumption being made that points in the cross section which lie on a straight line before, will lie on a straight line after the load is applied. Figures 7 and 8 are drawn from the deflection data given in the foregoing tables and indicate that this assumption is reasonable.

Similar plats have been made for the second panel point and the tip of the wing with results that agreed with those shown in Figures 7 and 8. The discrepancies from a straight line deflection as shown above are matters of one or two tenths of an inch, part of which may be accounted for by the precision of the deflection data. It may therefore be said that the assumption that the wing is deflected and rotated by the air load without appreciable distortion is correct except, possibly, very near to the wing root.

From the above assumption it may readily be seen that the vertical movement of any spar due to the rise and rotation of the cross section will equal $v+\theta d$; v the vertical deflection, being positive when upward, θ being considered positive for counterclockwise rotation about the leading edge.

The running load on the spar necessary to produce this deflection equals

$$w=kI(v+\theta d) \qquad 1$$

Multiplying equation 1 by d we get

$$wd=kId(v+\theta d) \qquad 2$$

But wd=the moment of the load about the leading edge and for equilibrium it is necessary that

$$\Sigma w-F=O \qquad 3$$

and

$$\Sigma wd-M=O \qquad 4$$

By equations 1 and 3

$$F/k=v\Sigma I+\theta\Sigma(Id) \qquad 5$$

By equations 2 and 4

$$M/k=v\Sigma(Id)+\theta\Sigma(Id^2) \qquad 6$$

For convenience let

$$\Sigma I=a$$
$$\Sigma(Id)=b$$
$$\Sigma(Id^2)=c$$

whence and

$$\left.\begin{aligned}F/k&=va+\theta b\\ M/k&=vb+\theta c\end{aligned}\right\} \qquad 7$$

Solving these simultaneous equations we get

$$\theta=\frac{bF-aM}{k(b^2-a)} \text{ and } v=\frac{cF-bM}{k(ac-b^2)}=\frac{bM-cF}{k(b^2-ac)}$$

Substituting these values in equation 1, gives

$$w=\frac{I}{b^2-ac}(bM-cF+(bF-aM)d) \qquad 8$$

Equation 8 gives the running load per unit length on the spar at the section under consideration. Once this loading is known, the shearing forces, bending moments, and fiber stresses may be calculated by the usual procedure for cantilever beams.

When designing a wing such as the Junker having the spars placed as shown in Figure 9, it will be necessary to provide "ghost spars," represented by the dotted lines in the figure. These imaginary members should be placed vertically above or below the actual members, the actual cross-sectional area being assumed as equally divided between the existing member and its ghost. The computations are then carried on as in the ordinary case.

The value of k for a cantilever of uniform cross section under uniform load may be obtained by substituting Δ for $(v+\theta d)$ in equation 1, where $\Delta=\frac{w}{2EI}\left(\frac{x^4}{12}-\frac{L^3x}{3}+\frac{L^4}{4}\right)$, x being measured from the free end of the cantilever, whence

$$k=\frac{2E}{\frac{x^4}{12}-\frac{L^3x}{3}+\frac{L^4}{4}} \qquad 9$$

At the wing tip $x=O$ and $k=\frac{8E}{L^4}$

At the wing root $x=L$ and $k=\propto$

For cases where the spars are not of uniform section, as in tapered wings, or where the load is not uniform, the deflection may be found by the graphical method described on pages 225 to 232 of Fuller and Johnston's Applied Mechanics, Volume II, or that in article 173 of the McCook Field Handbook, Structural Analysis and Design of Airplanes, or in Information Circular No. 213.

The values of w for the several sections along the spar as given by equation 8 of this report are to be used when plotting the loading diagrams. The values of k, θ or v will, however, seldom be needed, and it is to be noted that results obtained from them will be approximate.

The application of this rational formula to the third panel point of the three-spar wing gives the following results:

LOW INCIDENCE.

$F=1$ lb.

$M=F\times$distance to $C.\ P.=1\times50=50$ in. lbs.

$a=\Sigma I=86+117+72=275$ in.[4]

$b=\Sigma(Id)=86\times15+117\times40+72\times65=10{,}650$ in.[5]

$c=\Sigma(Id^2)=86\times15^2+117\times40^2+72\times65^2=510{,}900$ in.[6]

$$W_F=\frac{86}{10{,}650^2-275\times510{,}900}\Big[10{,}650\times50-510{,}900\times1+(10{,}650\times1-275\times50)15\Big]$$

$$=\frac{86}{-27{,}100{,}000}\Big[21{,}600+(-3{,}100)15\Big]=\frac{86\times24{,}900}{27{,}100{,}000}=7.9\%$$

$$W_C=\frac{117}{-27{,}100{,}000}\Big[21{,}600+(-3{,}100)40\Big]=\frac{117\times102{,}400}{27{,}100{,}000}=44.2\%$$

$$W_R=\frac{72}{-27{,}100{,}000}\Big[21{,}600+(-3{,}100)\,65\Big]=\frac{72\times180{,}000}{27{,}100{,}000}=47.9\%$$

HIGH INCIDENCE.

$F=1$ lb.

$M=F\times$distance to $C.P.=1\times33=33$ in. lbs.

a, b, c, remain as above.

$$W_F=\frac{86}{27{,}100{,}000}\Big[10{,}650\times33-510{,}900\times1+(10{,}650\times1-275\times33)\ 15\Big]$$

$$W=\frac{86}{27{,}100{,}000}\Big[-155{,}900+(1{,}480)15\Big]=\frac{86\times133{,}700}{27{,}100{,}000}-42.4\%$$

$$W_c=\frac{117}{27{,}100{,}000}\Big[-155{,}900+(1{,}480)40\Big]=\frac{117\times96{,}700}{27{,}100{,}000}-41.7\%$$

$$W_R=\frac{72}{27{,}100{,}000}\Big[-155{,}900+(1{,}480)65\Big]-\frac{72\times59{,}700}{27{,}100{,}000}-15.9\%$$

By comparing the results obtained from this rational formula with those based on the sand test data, it will be seen that the distribution as given by the formula is conservative for the design loads in the front and rear spars while for the center spar the design load agrees very closely with the actual load.

From a study of these results in relation to those from the sand test it appears that part of the load is transferred from the rear to the front spar in low incidence and from the front to the rear spar in high incidence. This is logical when it is considered that the front spar, being designed for high incidence loading, has a reserve of strength and stiffness under low incidence, but since the interspar trussing acts to make the front spar deflect with the center and rear spars, additional stresses are developed in it, due to forces causing this extra deflection. The same effect is noticeable in the case of the rear spar in high incidence.

In the development of the rational formula no provision is made for the fact that, due to the rotation of the wing sections, the value of F and the position of the center of pressure will vary at different parts of the wing since the angle of attack is changed. It is obviously impossible to provide for this action by any simple method. The effect of this rotation of the aerofoil is, in most cases, to move the center of pressure toward the rear in low and toward the leading edge in high incidence, so that the distribution given by the rational formula tends toward the unsafe side. This tendency will partially offset the previously noted conservatism.

It is to be remarked, too, that the deflections will not serve as absolute criteria for the distribution of the load since no account is taken of the effect on the deflections of the tensions or compressions developed in the spars by the drag trussing, the direction of the deflection of a trussed cantilever under an axial loading being determined by the arrangement of the web members.

The stresses developed in the spars by the drag forces, i. e., the forces parallel to the chord, should be calculated in the usual manner by finding the neutral plane perpendicular to the chord and applying the beam theory. The drag loads are to be applied to the leading or trailing edge according as to which will cause the greater stresses in the members of the drag truss.

DISTRIBUTION IN PROPORTION TO DISTANCE FROM CENTER OF ROTATION.

A second rational method of attack suggests itself when a section of the wing is considered, as shown in Figure 10. We then have a cross section which acts as a unit, subjected to an eccentric load. The spars, braced by the interspar trussing, develop stresses to resist this load in a manner very similar to the action of the rivets in an eccentrically loaded structural joint.

Figure 10 shows a section of the wing at the third panel point in low incidence under the action of a load, assumed as 100 pounds, for simplifying the computations, acting at the center of pressure with an inclination of 5° to the vertical.

The center of gravity of the area of the spars is obtained in the usual way.

$$\text{C. G. in horizontal axis}=\frac{.467\times60.6+.516\times121.2}{.638+.467+.516}=\frac{90.9}{1.621}=56.0''$$

G. C. in vertical axis=

$$\frac{.282\times17.28+.356\times40.65+.209\times17.55+.258\times40.38+.209\times17.55+.307\times41.04}{1.621}=32.2$$

The moment of inertia of the spars about the C. G.= $\Sigma\,(Ax^2)+\Sigma\,(Ay^2)$, x and y being the coordinates of the spars.

	$\Sigma\,(Ax^2)$	$\Sigma\,(Ay^2)$
Front	$0.356\times8.5^2=25.7$ $0.282\times14.9^2=62.6$	$0.356\times56.0^2=1{,}118$ $0.282\times56.0^2=885$
Center	$0.258\times17.2^2=76.4$ $0.209\times14.6^2=44.5$	$0.258\times4.6^2=5$ $0.209\times4.6^2=5$
Rear	$0.307\times9.5^2=27.7$ $0.209\times14.6^2=44.5$	$0.307\times65.2^2=1{,}305$ $0.209\times65.2^2=889$
	281.4	4,207

$I_0=4488$ in.^{4}

Stress due to bending, $f_b=\dfrac{M_0c}{I_0}$.

Stress due to shear, $f_s=\dfrac{F}{A}$.

The neutral axis lies in a line normal to the resultant air load "F" where

$$f_b=f_s$$

$$\frac{M_0c}{I_0}=\frac{F}{A}$$

$$M_0=Fx_0$$

$$c=\frac{I_0}{Ax_0}.$$

The distance to the neutral axis is therefore

$$c=\frac{4488}{1.621\times28.7}=96.4 \text{ to the left of the C. G.}$$

The stress at a point 1 inch from the intersection of the neutral axis and the line normal to the air force, i. e., from the center of rotation is $f=\dfrac{M_x1}{I}$.

$$M=F(x_0+c)=M_0+c=M_0+F\frac{I_0}{Ax_0}=F\left(x_0+\frac{I_0}{Ax_0}\right)$$

$$I=I_0+Ac^2=I_0+A\frac{I_0^2}{Ax_0}=I_0\left(1+\frac{I_0}{Ax_0^2}\right)$$

$$f=\frac{M}{I}=\frac{Fx_0\left(1+\frac{I_0}{Ax_0^2}\right)}{I_0\left(1+\frac{I_0}{Ax_0^2}\right)}=\frac{M_0}{I_0}$$

$$f=\frac{100\times28.7}{4488}=0.640.$$

The intensity of the stress in each spar will be normal to a line joining the spar and the center of rotation and will vary as the distance from the center of rotation.

STRESS IN SPARS IN LOW INCIDENCE.

Front	$0.64\times40\times0.356=9.0$	
	$0.64\times46.5\times0.282=8.3$	17.3%
Center	$0.64\times101\times0.258=16.6$	
	$0.64\times103\times0.209=13.6$	30.2%
Rear	$0.64\times161\times0.307=31.2$	
	$0.64\times162.5\times0.209=21.3$	52.5%

In high incidence the center of pressure is at 33 per cent of the chord and the angle between the resultant air force and a normal to the wing chord is 8°.

$$c=\frac{4488}{1.621\times12.3}=225''$$

$$f=\frac{100\times12.3}{4488}=.274.$$

STRESS IN SPARS IN HIGH INCIDENCE.

Front......	0.274×0.356×282=27.5	
	0.274×0.282×279=21.5	49.0%
Center....	0.274×0.258×224=15.8	
	0.274×0.209×219=12.5	28.3%
Rear.......	0.274×0.307×163=13.6	
	0.274×0.209×159= 9.1	22.7%

The second rational method is dependent upon the same assumption as the Burgess method, that the spar deflects and rotates without appreciable distortion, making the intensity of stress in any spar proportional to its distance from the center of rotation.

A comparison of the distribution given by this second method with that back figured from the sand test data shows that the computed stress in the front spar in low and the rear spar in high incidence are in accord, while the computed stress in the center spar is low. Although the method appears logical the results are not in sufficiently close accord with those determined from an actual test to warrant recommending it. By investigating the results it seems that the interspar trussing acts to distribute the stresses in a manner different from the computed distribution, in this case the increment being added to the center spar instead of going from the more heavily to the more lightly stressed exterior spar.

It is also interesting to note that the effect of a stiff metallic wing covering would be to increase the distance between the center of gravity of the section and its center of rotation. This increase would change the proportional distribution of the load among the spars by changing the relative distances of the spars from the center of rotation.

The load acting on a spar as determined by this method is really applied normal to the line connecting the spar and the center of rotation. For a rigid comparison of the results obtained by this formula with those from the sand test data the above fact should be taken into account and the loads as determined for each spar resolved into vertical and horizontal—lift and drag—components. For clarity, in Figures 10 and 11 this resolution has been omitted, its effect in this case being very small. It is interesting to note, however, that in the low incidence condition this resolution of the force in the upper chord of the center spar indicates an anti-drag component in this member.

This second rational formula is offered for consideration in future studies of tests made on multispar wings, since it is a logical method of attacking the load distribution problem. It is not recommended for use in design, however.

RESULTS OF EXTENSOMETER MEASUREMENTS.

Extensometer measurements were made near the root of the wing on the tension tubes of each spar during the sand test. Owing to difficulties in setting the gauge and the limited number of readings taken before failure occurred in the wing, the results obtained were not satisfactory. Those for the low incidence loading are given in Table 9, as they form a reasonable check on the distribution computed from the sand test data. The results in high incidence were valueless and are not included.

TABLE 9.—*Distribution of load at third panel point by various methods expressed in per cent of the load applied at the center of pressure.*

Method.	Low incidence.			High incidence.		
	Front spar.	Center.	Rear spar.	Front spar.	Center.	Rear spar.
1. Sand test data	22.9	42.8	34.3	36.9	41.8	21.3
2. Distribution proportional to moments of inertia	31.3	42.5	26.2	31.3	42.5	26.2
3. Distribution proportional to load between mid points of adjacent panels	25.8	23.4	50.8	51.3	27.1	21.6
4. Substitution of imaginary spars	6.5	47.0	46.5	42.2	43.7	14.1
5. Burgess's rational method	7.9	44.2	47.9	42.4	41.7	15.9
6. Distribution by distance from center of rotation method	17.3	30.2	52.5	49.1	28.3	22.8
7. Extensometer (distribution at wing root)	25.7	35.5	38.8	......	......	......

CONCLUSIONS AND RECOMMENDATIONS.

The available data on stress distribution in multispar wings are insufficient to permit investigations and satisfactory comparisons of the results obtained by the various methods of attacking this problem. It is recommended that care be taken during all tests of multispar wings to obtain data that will be useful in developing a satisfactory formula for the load distribution. Since, as has been noted, the deflections can not be taken as absolute criteria of the stresses existing in a trussed spar, when the spar is subjected to tension or compression such as is developed by the drag trussing of an internally braced wing, it seems advisable to use an extensometer and obtain the actual strains at various sections in the spar. The strains being known, it is a simple matter to obtain the actual stresses, to which the stresses computed by the various formulae can be compared and recommendations made regarding the method most satisfactory for use in design.

Basing our conclusions on the results of a single test, Burgess's rational method appears to give the most satisfactory agreement with the load distribution back-figured from the actual deflections. A study of the results compiled in Table 9 shows that the load given by this method agrees quite closely with that developed in the center spar, while it also gives conservative design loads for the front and rear spars. This case indicates that the structure so designed would be somewhat heavy due to this conservatism. The method is, however, recommended for use in design without any attempts at modification until sufficient investigations based on test data for multispar wings have been made to warrant the alteration of the Burgess formulae or the introduction of empirical constants to provide a reduction of the design load.

As a result of this investigation the rational formulae developed by Mr. Burgess are therefore recommended when calculating the distribution of the load among the spars of a multispar wing for use in design.

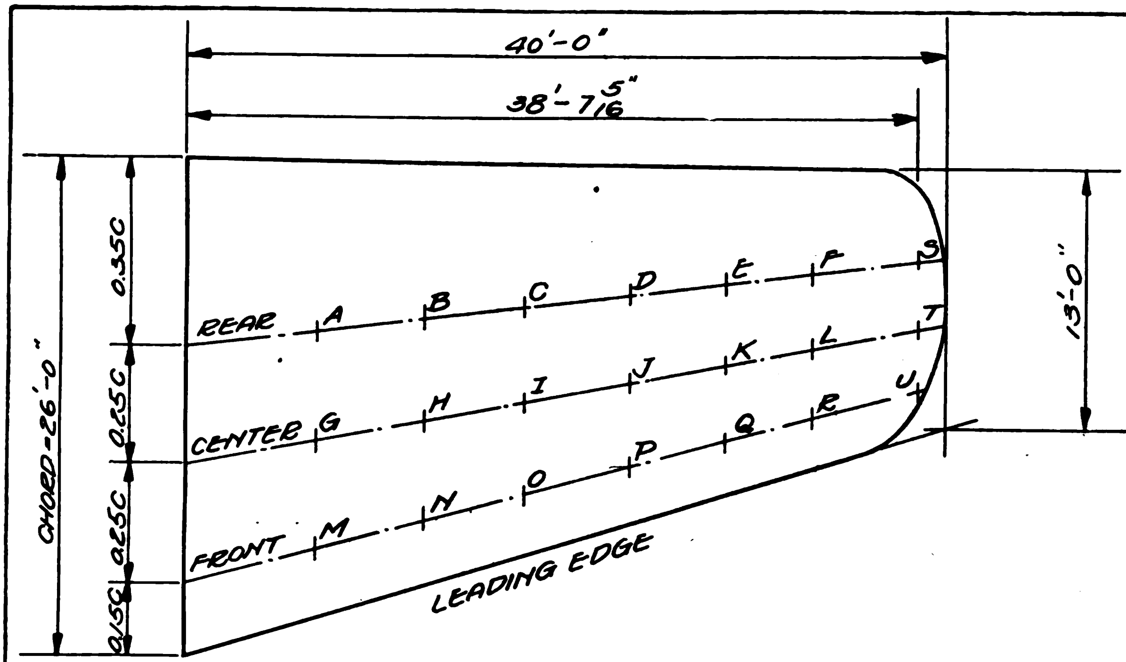
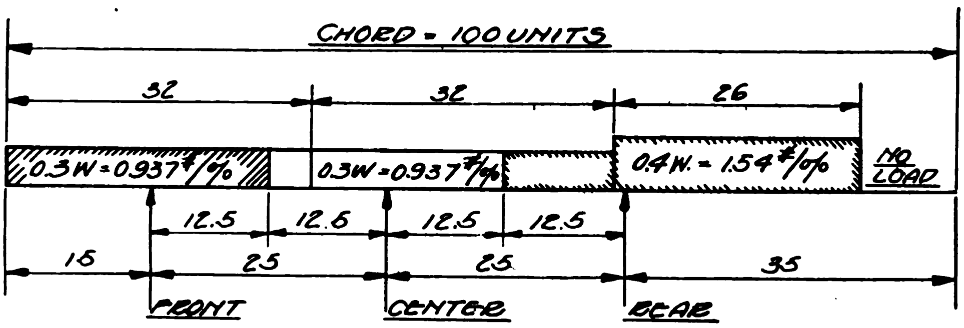


FIG. 1



LOW INCIDENCE LOADING

FIG. 2

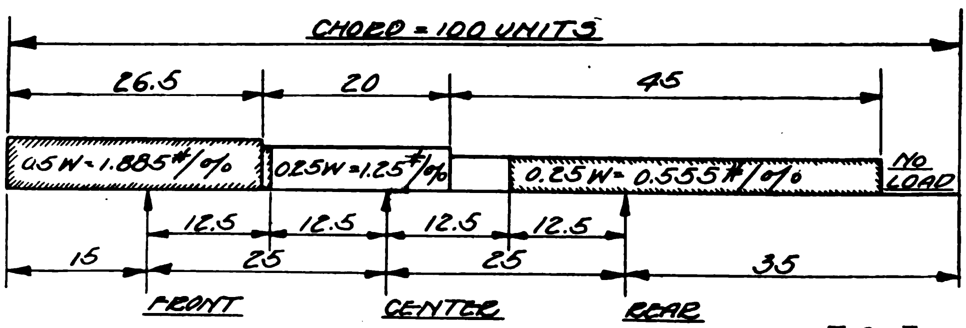
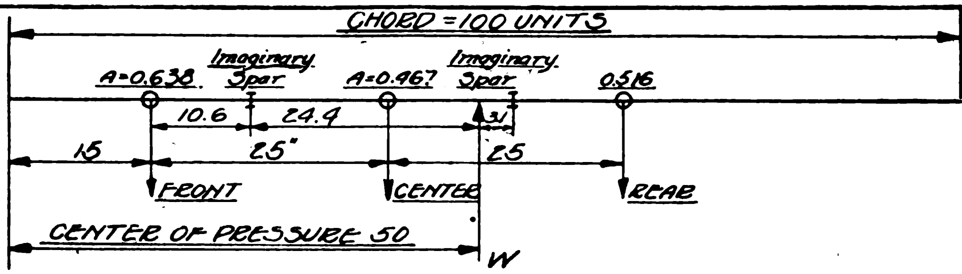


FIG. 3.

HIGH INCIDENCE LOADING

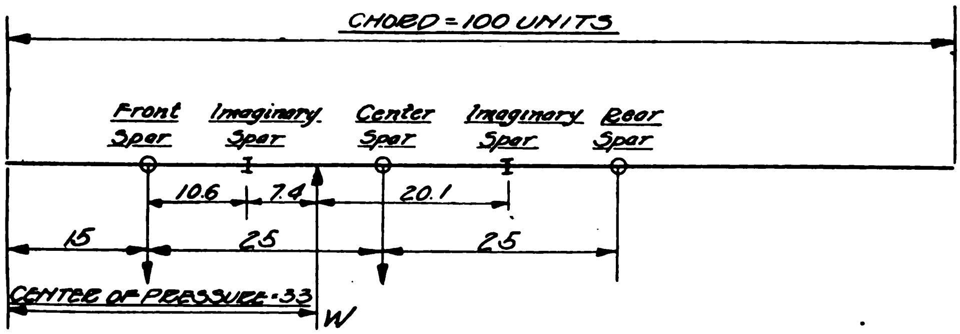
FIGS. 1, 2, and 3.



LOW INCIDENCE

THIRD PANEL POINT FROM ROOT

FIG 4



HIGH INCIDENCE

THIRD PANEL POINT FROM ROOT

FIG 5

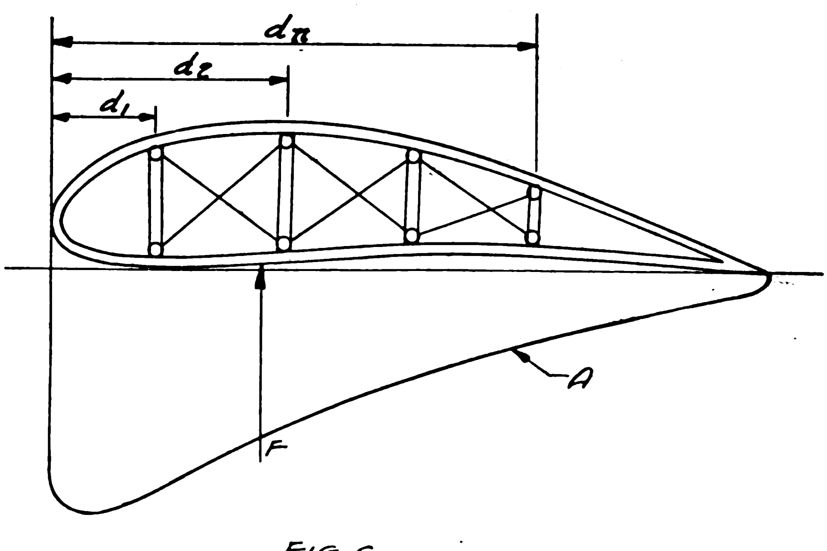
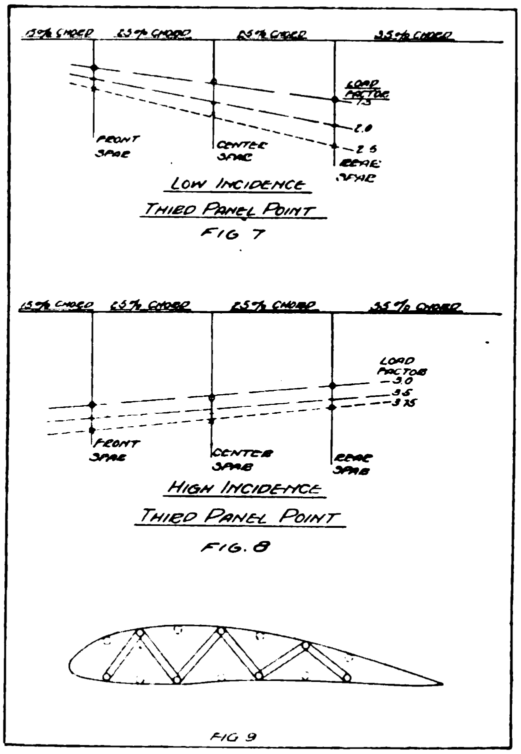


FIG 6

FIGS. 4, 5, and 6.



Figs. 7, 8, and 9.

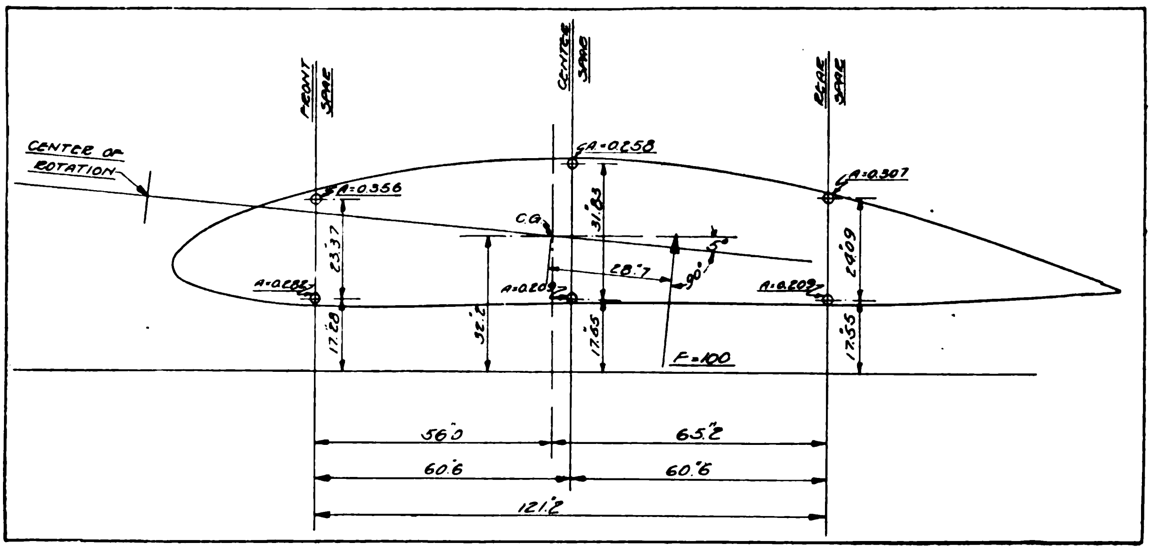


Fig. 10.—Low incidence.

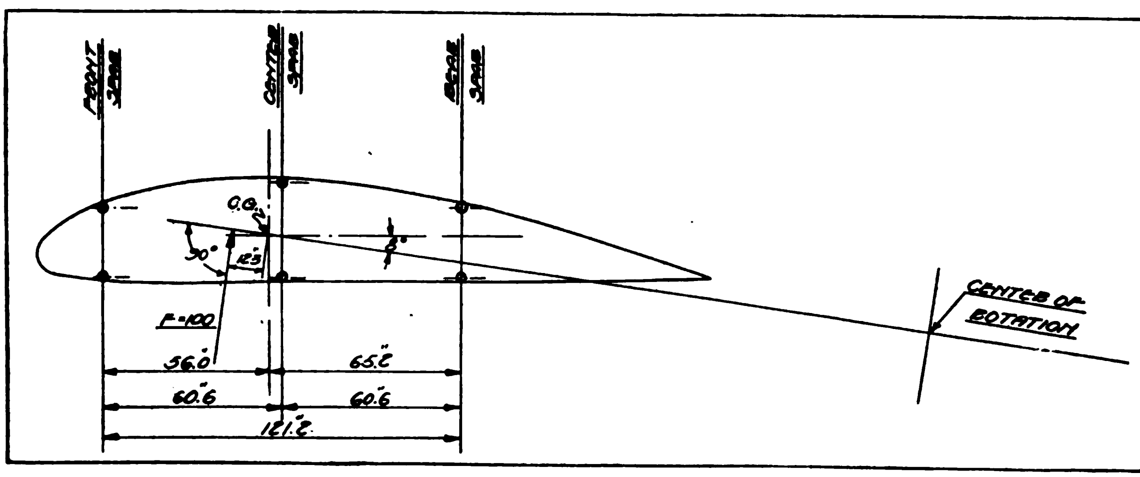


FIG. 11.—High incidence.
Note:—Spar areas and position of center of gravity are the same as fig. 10.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV February 15, 1923 No. 395

COMPARISON OF COLUMN FORMULAS

(AIRPLANE SECTION REPORT)

▽

Prepared by J. S. Newell and A. S. Niles, jr.
Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 22, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

COMPARISON OF COLUMN FORMULAS.

GENERAL CLASSIFICATION OF COLUMN FORMULAS.

The column formulas encountered in current practice may be classified quite satisfactorily in one of the following groups:

1. A combination of a "straight line" and the Euler formulas.
2. A combination of a "conic section" and the Euler formulas.
3. The Rankine formula or a derivative of it.
4. Scheffler's eccentricity formula or a modification.

Of all these formulas, that due to Euler is the only one having a purely rational derivation. Practical columns, however, almost never fulfill all of the conditions on which Euler's analysis depends, namely, that the column must be homogeneous and of uniform cross section throughout its entire length, must have a constant modulus of elasticity, and be originally perfectly straight. The loading, too, is assumed as being applied exactly at the centroid of the end cross section and acting truly parallel to the axis of the column. Johnson, Bryan, and Turneaure in Part III of "Modern Framed Structures" study the effect of accidental eccentricities by applying the eccentricity formula

$$fa=\frac{fc}{1+\frac{ec}{\rho^2}\sec\frac{L}{2}\sqrt{\frac{P}{EI}}}$$

in which they assume values of the $\frac{ec}{\rho^2}$ term to cause 10, 20, 30, and 40 per cent secondary stress in the column. The results are shown in Figure 1, and it is easily seen that the effects of accidental eccentricities for values of L/ρ between 40 and 100 are of much greater importance than at any other point in the entire range from 0. to ∞.

This is just the range in which practically all columns used in building or bridge construction are to be found, which is sufficient reason for the average structural engineer's lack of consideration for the Euler formula. Laboratory tests, however, prove that Euler's formula holds for short columns down to a point where the intensity of the stress on a cross section exceeds the elastic limit of the material, or nearly to the point where the intensity of the stress exceeds the yield point and causes a pure compression failure. Such loads can not be obtained in practice due to deviations of the ordinary structural column, or the method of loading from the ideal.

COMPARISON OF TYPES OF FORMULAS.

Then, too, long slender columns are not desirable in bridges or buildings due to their lack of rigidity, to difficulty of transportation and erection without injury and to their liability to failure under accidental loads, such as might occur on a bridge. The limiting value of L/ρ usually specified in American practice is 120 for main members and not over 200 for secondary members, the usual range for main members being from 40 to 70. Since this is the range in which Euler's formula is most susceptible to the deviations between practical and ideal conditions much thought and energy have been devoted to the development of a formula that will give satisfactory results for this range of L/ρ when compared with test specimens. For ease of application the straight-line type of formula can not be surpassed, and there are several now in use. In fact, the straight-line formula has now become the generally accepted practice for designing bridge members, the main cause of controversy being as to which line best represents the results of tests. Bridge and building specifications also generally limit the range of L/ρ to 120, or possibly 140, for main compression members, the result being that there is little information available on long, slender columns.

The airplane is perhaps the first structure of any importance in which long, slender columns are used for main members; hence means must be provided for obtaining safe design values that will not be uneconomical of material, since minimum weight is the ultimate criterion for an airplane structure of a given strength.

Figure 2 offers a basis of comparison of various formulas, all having been computed and plotted for the same data. It may be seen from this plot that the combination of the Johnson parabola

$$fa=fc-\frac{fc^2}{4\pi^2E}\left(\frac{L}{\rho}\right)^2$$

with the Euler formula

$$fa=\frac{\pi^2E}{\left(\frac{L}{\rho}\right)^2}$$

gives results that agree with the "eccentricity" and Natalis formulas for short columns, yet giving more economical results for longer columns. It is interesting to note that von Ostenfeld made a study of the more important column formulas in comparison with the better known test data and concluded that either the straight line or the parabola in combination with the Euler curve gave better agreement with the results of tests than did the eccentricity formula. His method was to compute the constants in various empirical formulas by use of the test data and get their mean error by the method of least squares. He states that the Rankine formula gave the largest mean error, while the parabola-Euler combination most nearly agreed with the test data. Salmon, on page 231 of his excellent work "Columns," concurs with these results and states that this combination of the Johnson parabola with the

Euler curve possesses the following advantages over other column formulas:

1. More accurate agreement with the average ultimate strength of concentrically loaded specimens.
2. Ease and simplicity of application.
3. A definite connection between the constants in the formula and the properties of the material.
4. Ease in determining the necessary area of a cross section under a given load.

Being susceptible to graphical treatment, which greatly decreases the labor involved in their use, these two formulas when used in combination, the point of tangency being where the allowable load is one-half the ultimate, appear to offer the best solution of the question of a formula that will give satisfaction over the entire range of L/ρ from zero to infinity.

Formulas based on conic sections other than the parabola may be eliminated on the grounds of difficulty of application.

The Rankine formula is partially rational in its derivation, but empirical constants are introduced to provide for accidental eccentricities and deviations of the practical column from the ideal. The constants may be chosen to agree satisfactorily with any set of test data over a limited range of L/ρ, but if an attempt is made to provide for the whole range of variation in slenderness a curve is obtained that is unsafe for certain values and overconservative for others. The constants used in the curve in Figure 2 give uneconomical results throughout the entire range of L/ρ in comparison with the other formulas. Rankine's formula is therefore of little use in the design of airplane structures.

In Technische Berichte, Band III, Heft 6, Natalis gives a formula that is empirical in its derivation, yet having constants that depend only on the properties of the material. As may be seen from Figure 2, this formula gives a curve quite similar to the eccentricity formula but somewhat more conservative. The formula is

$$fa=\frac{1+C}{1+C+C^2} \text{ where } C=\frac{fc}{\pi^2 E}\left(\frac{L}{\rho}\right)^2$$

and is not so easy to apply as the parabola. It intersects the Euler curve at ∞, although it can be made to intersect at any point if the value of "n" be properly chosen and substituted in the general form of the equation where

$$fa=fc\left[\frac{1+\frac{\pi^2-1}{\pi^2}C}{1+\frac{\pi^2-1}{\pi^2}C+\frac{\pi^2-1}{\pi^2}C^2}\right]$$

where C is the same as in the above. This formula is interesting because of its method of derivation, but is not as easy to apply as the parabola-Euler combination and is not recommended.

The eccentricity formula derived by Scheffler

$$fa=\frac{fc}{1+\frac{ec}{\rho^2}\sec\frac{L}{2}\sqrt{\frac{P}{EI}}}$$

theoretically covers all types of columns, but is open to criticism since empirical constants must be introduced to provide for deviation between practical and ideal conditions. Johnson, Bryan, and Turneaure recommend that $\frac{ec}{\rho^2}$ be taken as $0.001\frac{L}{\rho}$, while the British Air Board specifies

$$\frac{ec}{\rho^2}=\frac{C}{\rho^2}\left[\frac{L}{600}+0.025\right]$$

which Major Wylie alters to

$$\frac{ec}{\rho^2}=\frac{C}{\rho^2}\left[\frac{L}{600}+0.025d_1\right]$$

where d is the internal diameter of a tube and c the distance from the center of gravity of a cross section to the extreme fiber. These latter two values appear to be excessive and have been found to agree more closely with the results of some British tests if divided by 4. The formula plotted in Figure 2 is known in British practice as the Southwell Formula, a modification of Scheffler's formula in which the term under the radical is changed from

$$\sqrt{\frac{P}{EI}} \text{ to } \sqrt{\frac{fo}{E\rho^2}}$$

The work involved in the use of this formula to determine the area of a cross section practically eliminates it, for unless curves have been drawn for the various materials, and for variations in the properties of a given material, the purely arithmetical labor involved becomes tedious. It does, however, agree quite closely with test data, although as von Osterfeld states it is not as good as the parabola in combination with the Euler curve.

From a standpoint of accuracy, economy of material, and ease of application the Johnson parabolic formula

$$fa=fc-\frac{fc^2}{4\pi^2 E}\left(\frac{L}{\rho}\right)^2$$

in conjunction with the Euler formula

$$fa=\frac{\pi^2 E}{\left(\frac{L}{\rho}\right)^2}$$

therefore appears to offer the best solution for a column formula for use in the design of airplane compression members which have pin ends.

THE PROBLEM OF RESTRAINED ENDS.

Although the above discussion and comparisons have been based on formulas for pin-ended columns, the same conclusions could be drawn as to the applicability of the various methods to fixed or restrained ends, since different end conditions may be provided for by changing the constants in any of the formulas. In the parabola-Euler combination this change is made by the introduction of a constant C, and the formulas take the following form:

$$fa=fc-\frac{fc^2}{4C\pi^2 E} \text{ and } fa=\frac{C\pi^2 E}{\left(\frac{L}{\rho}\right)^2}$$

For the condition of rigidly fixed ends C may be developed rationally and will be found to equal 4; for one end fixed and one hinged C becomes 2.25. For ends that are restrained in some other way the value of C to be used is entirely a matter of judgment. In airplane construction, where light members are connected to other light members,

a rigidly fixed end is impossible to attain. In fact, the experience at McCook Field indicates that a "fixity coefficient" of 2 represents about the maximum degree of restraint obtainable in ordinary airplane structures. This evidently represents a condition between a column pinned at both ends and one with one fixed and one pin end, although such a comparison is futile since, while the ends are restrained, they do not compare with any of the theoretical end conditions. Two (2) is therefore recommended as the maximum "fixity coefficient" to be used in airplane design, so the designer is confronted with the problem of choosing a coefficient between that and unity. This is purely a matter of judgment as to the degree of fixity attainable with a given joint, so that the question reduces to one of experience.

The same result can be obtained by assuming points of inflection in a restrained strut and using the formulas for pin ends, except that the distance between the points of inflection is to be used for the length. The effect of this is the same as using a "fixity coefficient" for it may be shown that with both ends rigidly fixed the points of zero moment will be at the quarter points, that is, that $L^1=\frac{L}{2}=\frac{L}{\sqrt{C}}$. The length corresponding to a fixity of 2 is $L^1=\frac{L}{\sqrt{2}}=0.707L$. In other words the distance between points of inflection varies as the square root of the coefficient of fixity. The two methods give the same results and are equally dependent upon the judgment of the designer for their accuracy when applied to any specific case. For the parabolic and Euler formulas it is easier to use the coefficient of fixity than a new length, but for the Rankine, Eccentricity, or Natalis formulas the assumption as to the location of the points of inflection is probably as easy, or easier, to use.

CONCLUSION.

Since so much is left to the judgment of the designer as to the use of a constant for other than pin-ended columns it is ridiculous to advocate any one formula as having greater accuracy than the others, for a slight change in the value of C chosen will more than offset the differences obtained by any two formulas. Hence the formula that is easiest to apply becomes all the more desirable and for this reason as well as for the accuracy of the results to be obtained the combination of the Johnson parabolic with the Euler formula is recommended for the design of all airplane struts and columns.

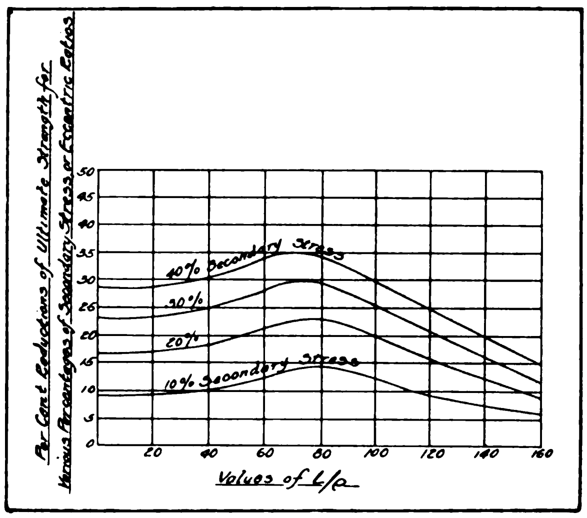
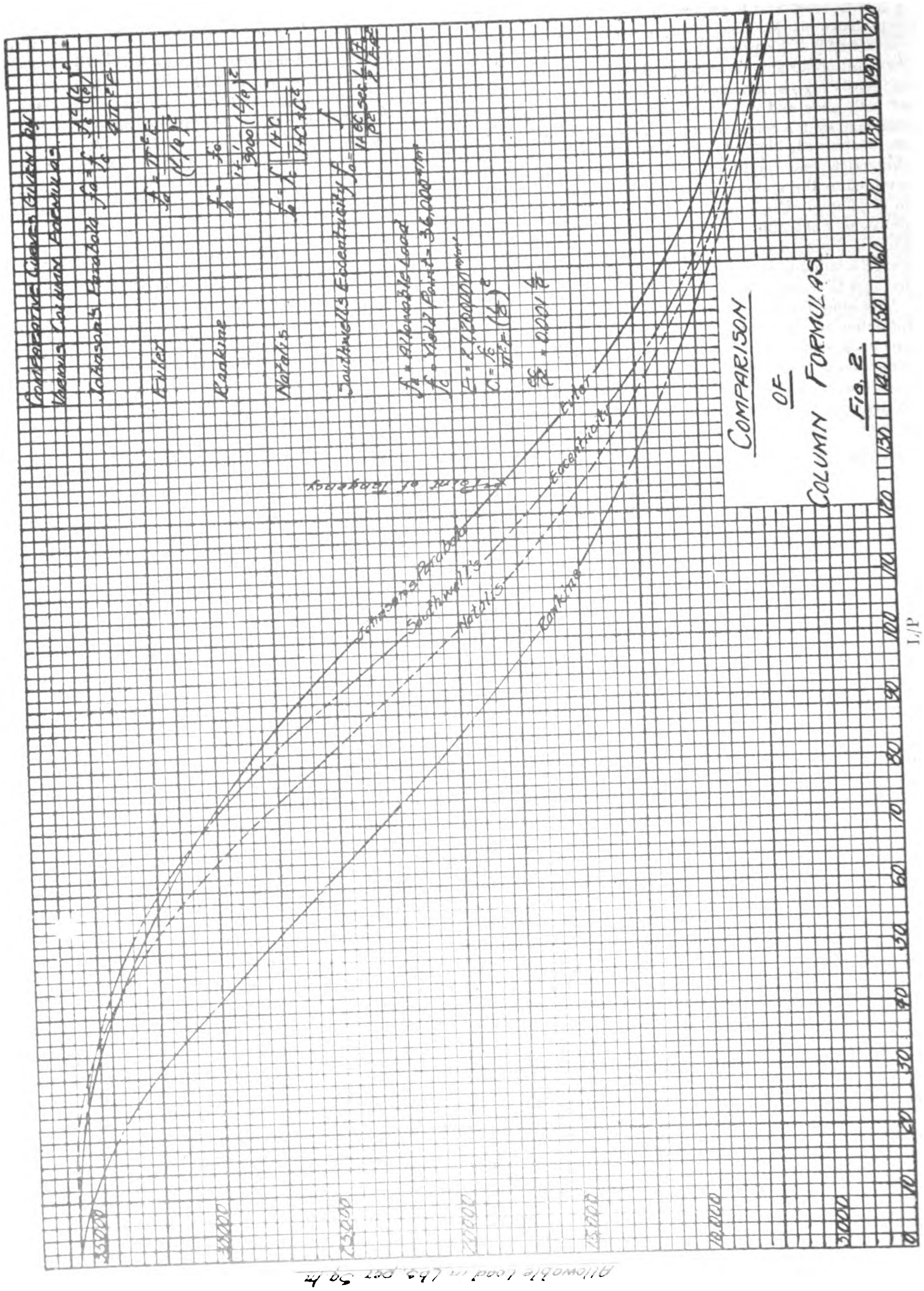


FIG. 1.—Effect of secondary stress or eccentric loads on columns. From Johnson, Byran, Turneaure, "Modern Framed Structures," Part III, page 58.


Comparative Curves Given by Various Column Formulas
Johnson's Parabola
Euler
Rankine
Natalis
Southwell's Eccentricity
Point of Tangency
Southwell's
Eccentricity
COMPARISON OF COLUMN FORMULAS
FIG. 2.
L/P
Allowable Load in Lbs per Sq In
35,000
30,000
25,000
20,000
15,000
10,000
5000

File No. A10 23/177. (C. A. S. I. C. 1)

AIR SERVICE INFORMATION CIRCULAR

(AVIATION).

CHANGE No. 1.

WAR DEPARTMENT, AIR SERVICE, *August 1, 1923.*

Page 2, column 1, Air Service Information Circular, Volume IV, No. 395, "Comparison of Column Formulas," beginning with the word "and" below the first formula, and up to and including the second formula, is corrected by direction of the Chief of Air Service, in accordance with a recommendation of the Engineering Division contained in letter of June 9, 1923, to read as follows:

Page 2, column 1, beginning with the word "and" under first formula, up to and including the second formula, substitute the following:

and is not so easy to apply as the parabola. It intersects the Euler curve at ∞, although it can be made to intersect at any point if the value of "n" be properly chosen and substituted in the general form of the equation where

$$fa = fc\left[\frac{1+\frac{n^2-1}{n^2}C}{1+\frac{n^2-1}{n^2}C+\frac{n^2-1}{n^2}C^2}\right]$$

56235—23

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1923

CONFIDENTIAL
File D 72.13/49

McCOOK FIELD REPORT, SERIAL No. 2007

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV | February 15, 1923 | No. 396

TEST OF MACHINE GUN SYNCHRONIZER TYPE C-8

(ARMAMENT SECTION REPORT)

▼

Prepared by
Lieut. H. A. Sutton
Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 29, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

TEST OF MACHINE GUN SYNCHRONIZER, TYPE C-8.

OBJECT OF TEST.

To determine the synchronizing and mechanical characteristics of machine gun synchronizer, Type C–8.

DESCRIPTION OF APPARATUS.

Machine gun synchronizer, Type C–8, was developed after test of the Type C–3 synchronizer. It also includes the principle developed in the Type C–2 synchronizer. The Type C–8 synchronizer is made in five units—the drive unit, generator unit, operating control unit, trigger motor unit, and impulse cable tube unit. This is done in order to avoid difficulty in keeping the parts in stock rooms and to facilitate quantity production.

The drive unit is similar in design to the drive unit for the Type C–1 synchronizer (Nelson gun control) and is installed in the same place on the engine. The housing 1, Figure 1, is serrated to provide an adjustment lock for the generator housing. The cam, as shown at 2, Figure 2, is fastened directly on the drive shaft. The same cam and drive gear is used as in the Type C–1 synchronizer drive unit. The assembled drive unit for the Wright 300-horsepower engine is shown in Figure 4.

The generator unit is shown in Figure 5. It consists of an aluminum housing which is attached to the drive unit by means of two bolts. The base of the generator housing is serrated to fit the top of the drive unit. Adjustment in synchronization is obtained by loosening the two bolts connecting the generator and drive units and turning the generator housing until the proper location is secured after which the connecting bolts are tightened. An arm shown, Figure 6, is supported in a self-aligning ball bearing at 2. The lower end of the arm rests against the face of the cam when in operation. The arm 3 is pivoted at 4 in the housing. Its lower end rests against the arm 7, Figure 1. At the upper end of part 3 the impulse cable is attached. It operates through a metal tube which may be adjusted by means of screw 5, Figure 6. The operating cable operates through the housing at 6, Figure 6, and is connected to the arm 7, Figure 1. When the arm 7, Figure 1, is not operating the spring 1, Figure 7, forces the arm 3, Figure 6, out of engagement with the cam and its lower end rests against a shoulder in the housing. The lower end of the arm 3 holds the lower end of cam 7 away from the cam in this position. A pull on the operating lever forces the lower end of arm 3 between arm 7 and the cam. Rotation of the cam transmits reciprocating motion to the impulse cable.

The operating control unit consists of a modified operating control and bracket unit as used in the Type C–1 synchronizer. This is shown in Figure 7. The operating plunger 1, Figure 7, engages with the end of arm 3, Figure 6. The trigger motor unit consists of a Type C–1 synchronizer trigger motor with a small bracket attached to support the end of the impulse cable tube as shown in Figure 9.

The impulse cable tube unit consists of a metal tube with two end couplings which attach to the trigger motor and generator. The unit is shown in Figure 10. The tube may be bent on a radius of not less than 6 inches. No braces are required between the gun and synchronizer generator. The generator is supported entirely from the drive unit. A guard as shown in Figure 11 is provided to inclose the generator.

DESCRIPTION OF TEST.

The apparatus was set up for ground test on the test stand shown in Figure 12. A firing test was made with the tube almost straight with results as shown in Figures 13 and 14. The tube was then bent as shown in Figure 12 and a firing test was made with results as shown in Figures 15 and 16. The synchronizer was then operated at 1,000 revolutions per minute for two hours. Overheating of the trigger motor plunger caused temporary suspension of the test. The trigger motor was replaced and the synchronizer was operated at 1,000 revolutions per minute for two hours. At the end of this time the synchronizer was disassembled for inspection. It was found that the impulse cable rocker lever and impulse cable hook were slightly worn. The synchronizer functioned perfectly throughout the test except for overheating of the Type C–1 synchronizer trigger motor. Packing of the generator with cup grease is necessary to prevent excessive wear and overheating. The impulse cable and tube showed little signs of wear and did not overheat excessively. Parts which showed wear were hardened to correspond to the hardness of other bearing surfaces. A few changes in design were suggested by the test and these changes have been made on the drawings.

RECOMMENDATIONS.

It is recommended that a small number of Type C–8 synchronizers be built according to assembly drawings X–39620, X–39630, X–39628, X–39632, and X–39663, and given a service test.

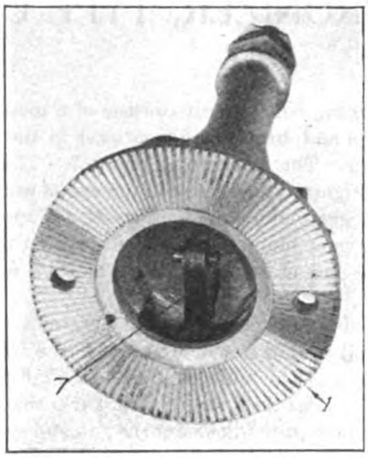


FIG. 1.—Generator assembly drawing X-39620.

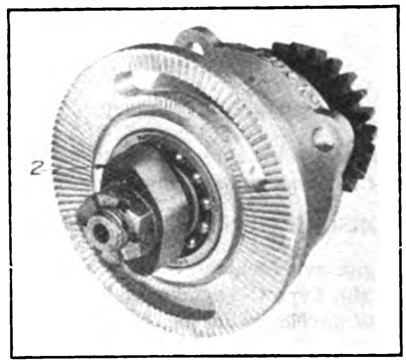


FIG. 2.—Drive unit for Wright engine.

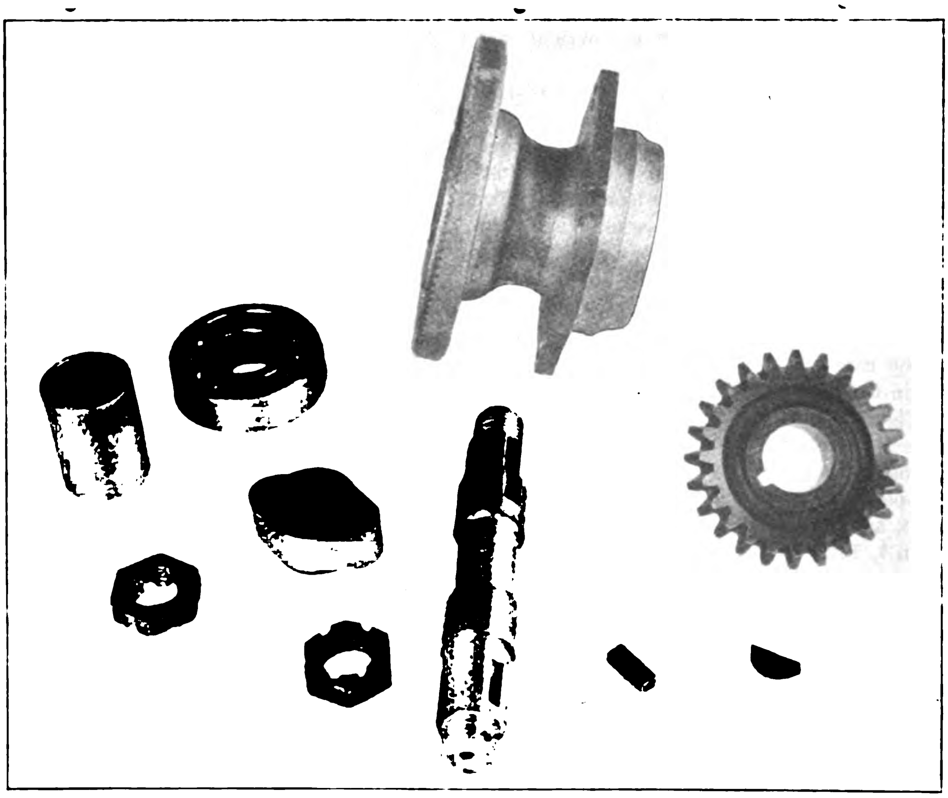


FIG. 3.—Drive unit for Wright engine disassembled.

FIG. 4.—Drive unit for Wright engine.

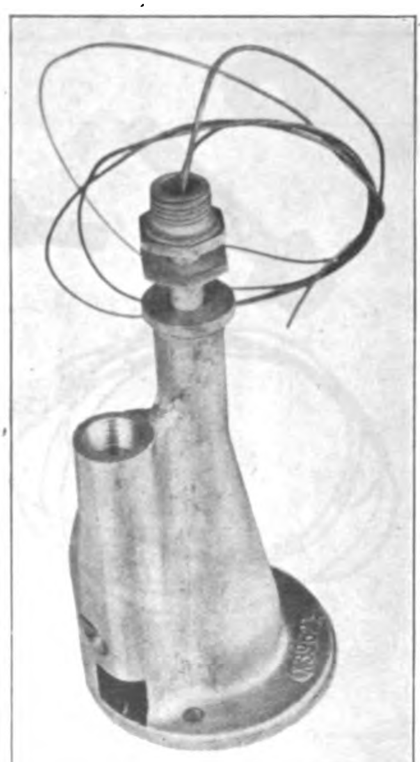


FIG. 5. Generator assembly drawing X-39620.

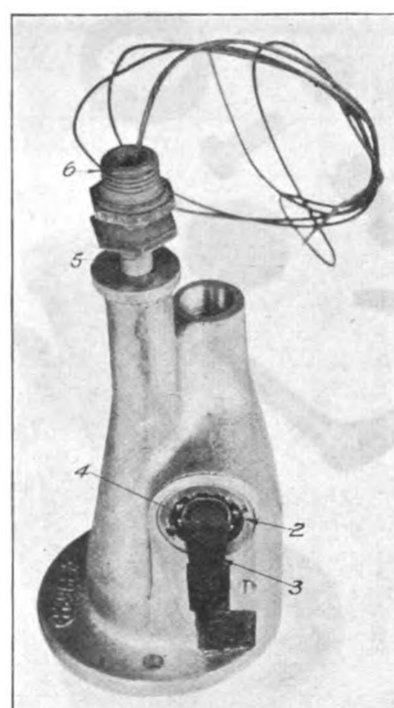


FIG. 6.—Generator assembly drawing X-39620.

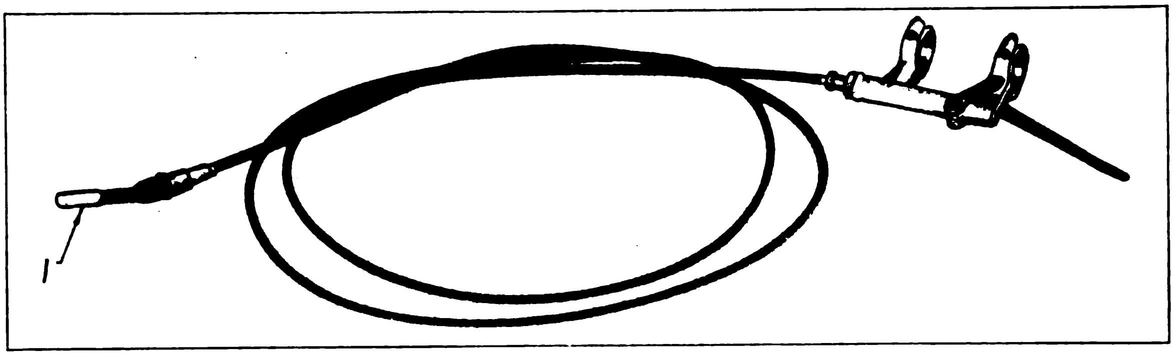


FIG. 7.—Control.

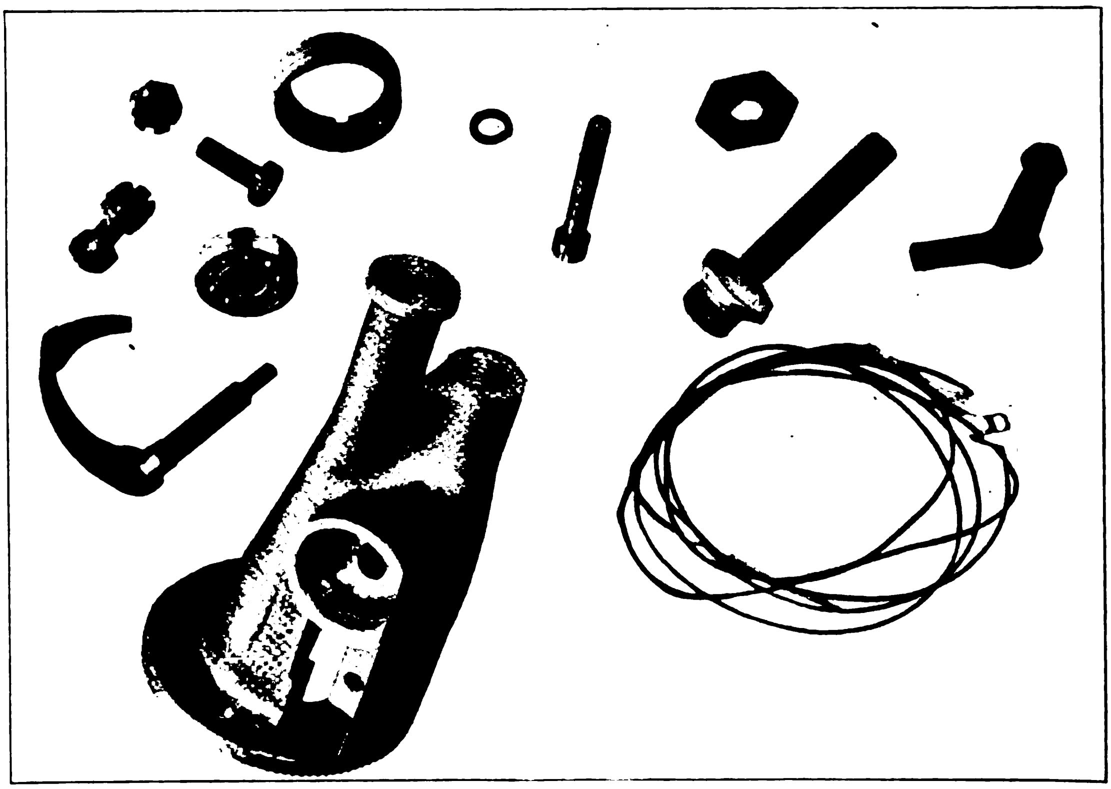


FIG. 8.—Generator disassembled.

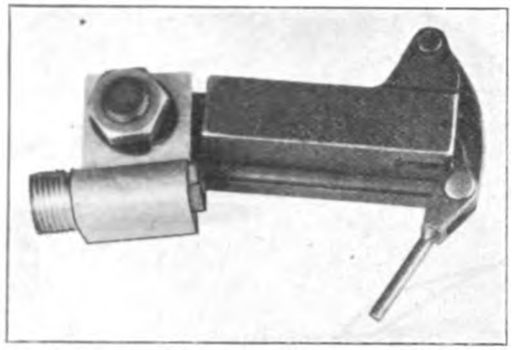


FIG. 9.—Trigger motor.

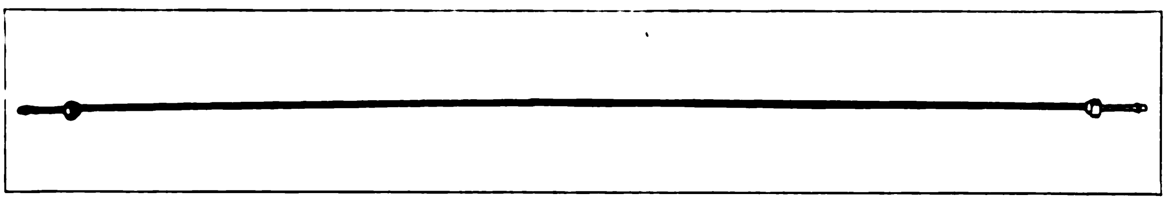


FIG. 10.—Impulse cable tube and end fitting.

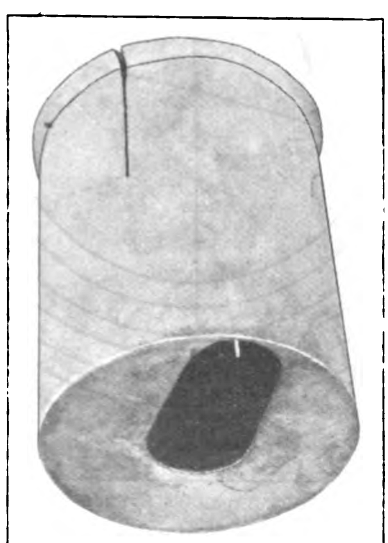


FIG. 11.—Generator housing guard.

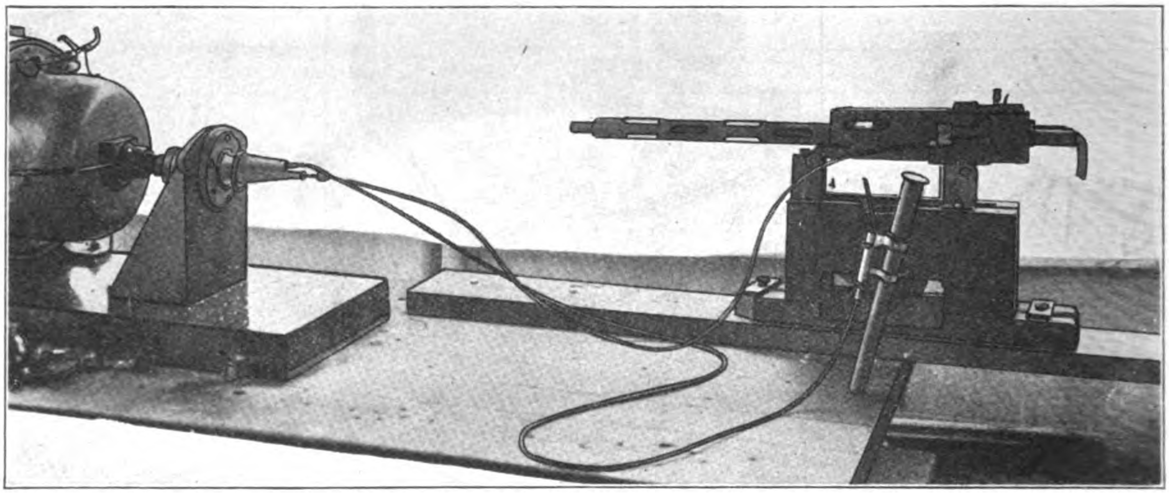


FIG. 12.—Assembled for ground test.

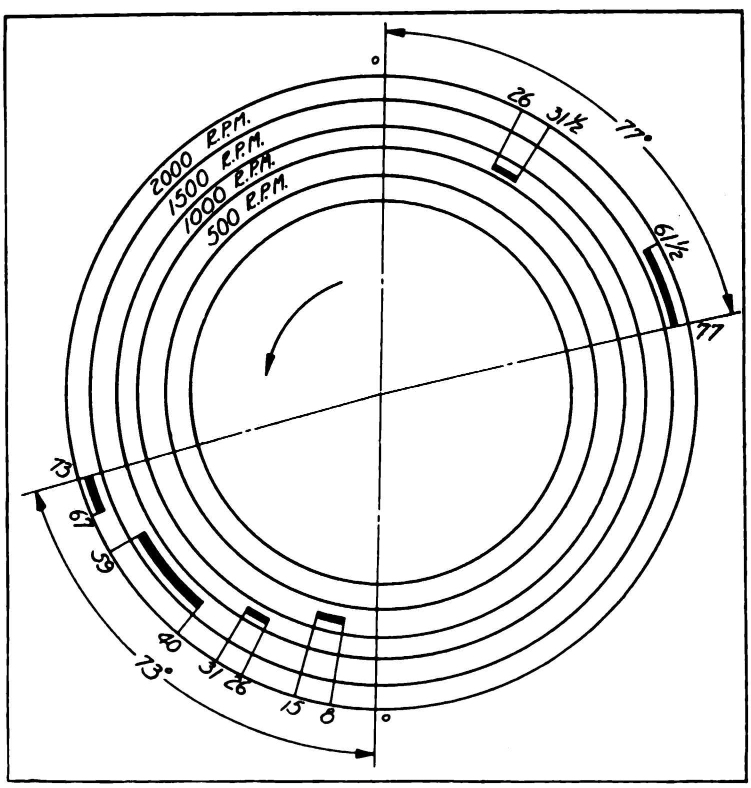


FIG. 13.—Machine gun synchronizer Type C-8. Browning machine gun, 30 cal. model 1918 MI, No. 55763. Distance of target from gun muzzle, 72 inches. Rounds per burst, 10. Date, June 27, 1922. E. O. 551-44. See figure 14.

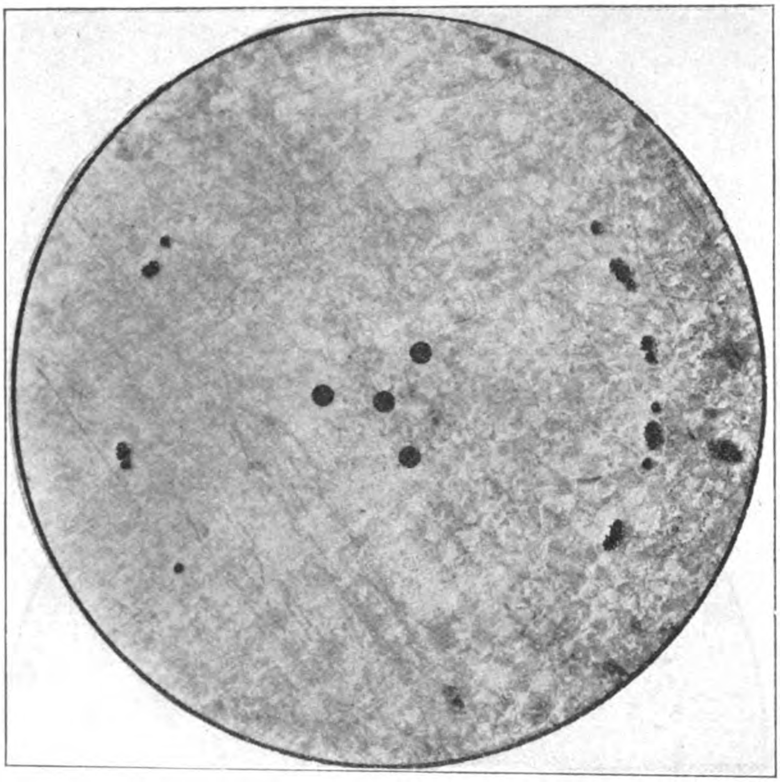


FIG. 14.—Results of firing test of machine gun synchronizer Type C-8.

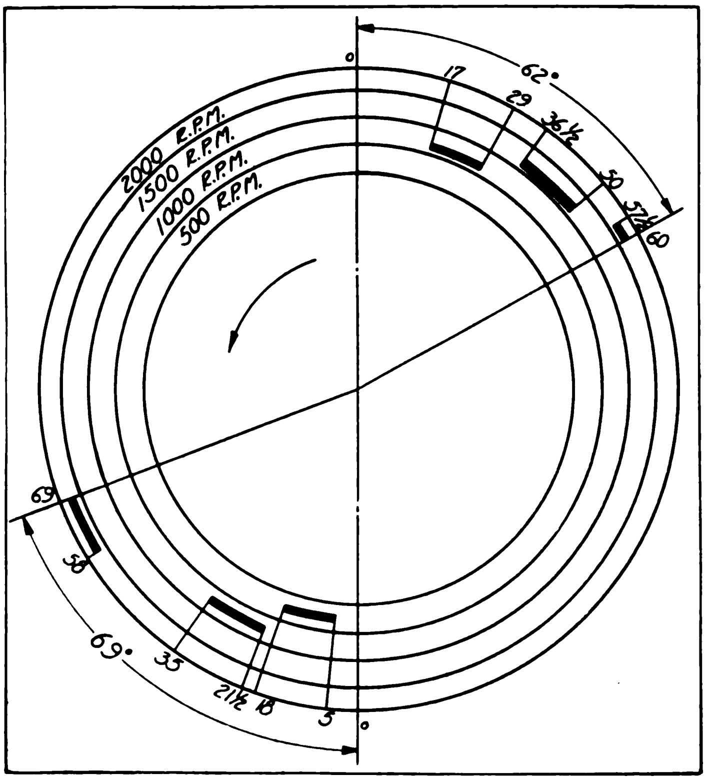


FIG 15.—Machine gun synchronizer Type C-8. Browning machine gun, 30 cal. model 1918 MI, No. 55763. Distance of target from gun muzzle, 61 inches. Rounds per burst, 10. Date, June 28, 1922. E. O. 551-44. See figure 16.

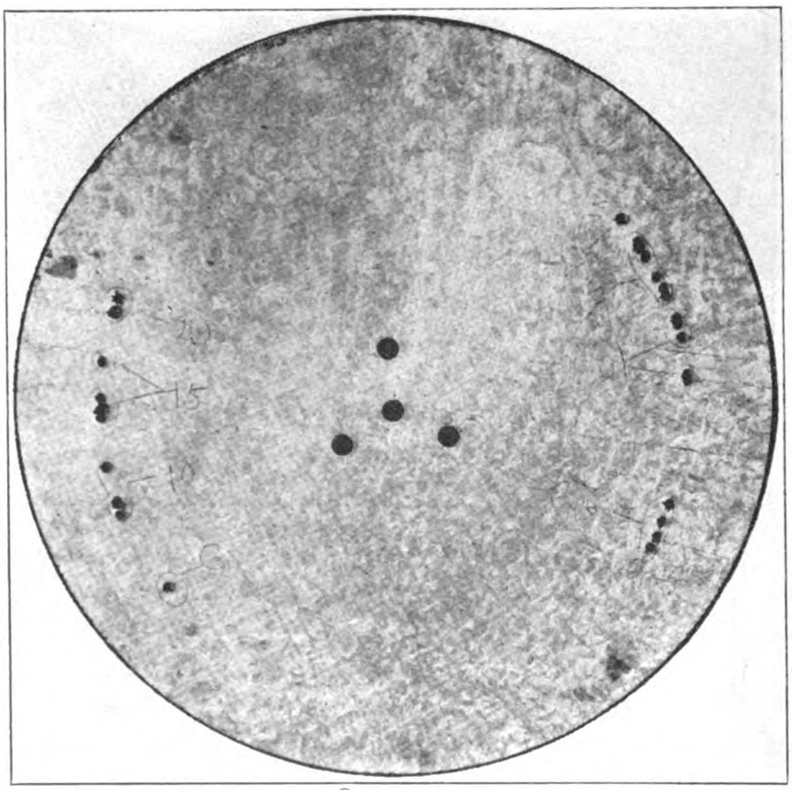


FIG. 16.—Results of firing test of machine gun synchronizer Type C-8.

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV February 15, 1923 No. 397

BAMBERG SPEED MEASURING STATION

(EQUIPMENT SECTION REPORT)

▽

Prepared by E. F. Bacon
Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 29, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CERTIFICATE.—By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

BAMBERG SPEED MEASURING STATION.

OBJECT.

The object of this report is to furnish information for the installation and operation of the Bamberg speed measuring station.

PRINCIPLE OF OPERATION.

The position of an aircraft in space can be determined if from two stations a known distance apart simultaneous readings are taken of the horizontal and vertical angles of the aircraft. If the readings are taken together every second, the course of the aircraft can be plotted both on a horizontal and vertical plane. (See fig. 1.) By computing the distance traveled in one second in each plane, the ground speed and the rate of ascent or descent are found. The absolute speed can be computed by adding vectorially the ground speed and the velocity of ascent or descent. The true air speed can be determined by means of a so-called wind star. This method is explained in detail under "Calculation of results."

The Bamberg speed measuring station consists of three recording theodolites, two of which are placed at the ends of a base line and the third at a point about midway between. Photographs of the horizontal and vertical scales are taken simultaneously at the three theodolites, the middle station serving as a check for the end stations. The instruments record together, due to the fact that the control circuit is a series arrangement of the shutter-tripping magnets. This control circuit can be closed either by a key or contact chronometer in the control house, or by the handle switch on one of the theodolites. The mechanism of the theodolite is such that the instant the current in the control circuit is stopped, the camera is recocked by a magnetic clutch energized by the local theodolite battery.

CONSTRUCTION AND OPERATION OF THEODOLITES.

Each theodolite consists of a telescope equipped with vertical and horizontal dials graduated to 30 seconds. At the point where these dials come together, they are provided with verniers. The verniers and scales are illuminated and their image thrown on the film by a combination lens and prism. The detailed operation of the mechanism can be explained by means of the wiring diagram of a theodolite as shown in Figure 2.

Assuming the camera to be cocked and switch (6) open, the cycle of operation is as follows when the control is from the control house:

Current is sent through the control line and passes through (1), causing magnet (2) to pull down arm (3), tripping camera and closing (6). When the control circuit is opened, (3) flies back and closes (4), allowing current to flow through magnetic clutch (7), which cocks camera and opens (6).

The cycle of operation when the control is from one of the theodolite handles is as follows:

The switch on handle (8) is closed, sending current through magnet (2), which closes contact (5) and operates the other theodolites. The rest of the cycle is the same as in the case of central control.

INSERTION OF THE FILM.

The cover of the camera box is removed and the film roll placed on the pin to the left of the camera, about 8 inches of the light protection paper having been previously unwrapped. This paper is threaded through the guide slit and over the small guide roll. The end of the paper is now put through the slit in an empty roll, which is then placed on the upper crank pin and turned until the roll catches on the small lugs on the base of the pin. The paper is adjusted so that it passes to the right of the sprocket wheel and is then pulled tight by holding the full roll and turning the empty roll. Before placing the cover back on the camera box the recording mechanism is set at about 190. After the cover is in position, the thumbscrew on the outside is pressed in and turned in the direction of the arrow until the point at which the film is attached to the paper is visible through the sighthole on the end of the camera box. The sighthole is then immediately closed so that the film will not become light struck. The number on the recording mechanism should now be noted and its flap closed. At the end of a test the number of the film should again be recorded and the remaining film rolled up by means of the thumbscrew before opening the camera box.

ELECTRICAL CONNECTIONS AT THE THEODOLITES.

The 8-volt storage battery which is provided with each theodolite for the operation of the motors and light must be connected to the instrument with its positive terminal to the positive binding post on the instrument. If the control is to be from one of the theodolite handles, the control wires must be connected to the terminals just above the battery binding post bars. If, on the other hand, the control is to be from the control house, the control wires should be connected to the binding posts marked "Central." When an observer is operating the control, the small slide in the handle of his instrument should be pulled out, but when the theodolites are operated from the control house, the slides on all the instruments should be in.

COMPLETE INSTALLATION AND SWITCHBOARD.

The control circuit consists of a series arrangement of the shutter-tripping magnets of the theodolites, a potential sufficient to cause a current flow of 0.25 ampere, and a device to close and open the circuit. The latter may be a Morse key or a contact chronometer in the control house, or the switch on the handle of one of the theodolites.

The switchboard contains three separate control circuits. When the top row of switches is down, the control is from the handle of the central theodolite. With the middle row of switches down, the control is from the Morse key; and with the lower row of switches down, the contact chronometer controls the circuit. Only one row of switches should be down at one time. The three separate diagrams are shown in Figures 3, 4, 5, the combined diagram in Figure 6, and the switchboard wiring in Figure 7.

OPERATION.

The operation of this station is as follows:

1. Close the circuit desired on the switchboard and adjust the potentiometer to give a current of about 0.25 ampere.
2. Adjust the films in the theodolites and record the number shown on the film counter of each instrument.
3. Locate the aircraft at the central station by means of the tripod telescope, and telephone the approximate position to the end stations.
4. At the end of the run, record the number on the film counter at each station.

CALCULATION OF RESULTS.

The graphical computor furnished with the speed measuring station is used to calculate the position of the aircraft from the theodolites.

To find the position of the aircraft with respect to the horizontal plane, or, in other words, to find its ground course, the two scales fitted with the swivel ends and the sliding sectors are used. They are mounted on a table with the two swivel ends a distance apart proportional to the length of the base line and to the scale on the arms. (See fig. 8.) The horizontal angles as registered on the films of the end stations are laid off by means of the sliding sectors. The point of intersection of the arms gives the ground location of the aircraft. The distance of this point from the ends of the base line is noted if the altitude is to be found.

The altitude is found by taking the distance measured from one end of the base line to the point of intersection of the two horizontal angles of the theodolites, laying this distance upon the wide scale of the small protractor triangle, setting the protractor to the vertical angle corresponding to the horizontal angle used and reading the altitude off the vertical scale. (See fig. 9.)

To determine the true air speed of the aircraft it is necessary to make use of the so-called wind star. This is accomplished as follows: The aircraft is flown level and at constant air speed in at least three different directions. The ground speed over these courses is determined by taking several readings of the theodolites at one-second intervals on each of the courses and calculating the ground speed. The ground velocities are then laid off in their proper directions from a point, by means of the protractor shown in Figure 10. The protractor is placed on the table with the 0–180° marks north and south. With the velocity vectors drawn in, the center of the protractor is moved down the wind velocity slide until it is so adjusted that the center of the protractor is at the center of the circle passing through the ends of the velocity vectors. The direction and velocity of the wind can now be read from the wind slide and circular scale. If a line is now drawn through this new center to the circumference of the circle the true air speed is obtained.

RECOMMENDATIONS.

It is recommended that both the aircraft and central control house be equipped with wireless telephone sets so that there will be no confusion as to the starting and stopping of any part of a test.

It is also suggested that tests be tried at night, as it would seem that a light would be very easy to follow with the theodolites and the wind conditions would be more satisfactory.

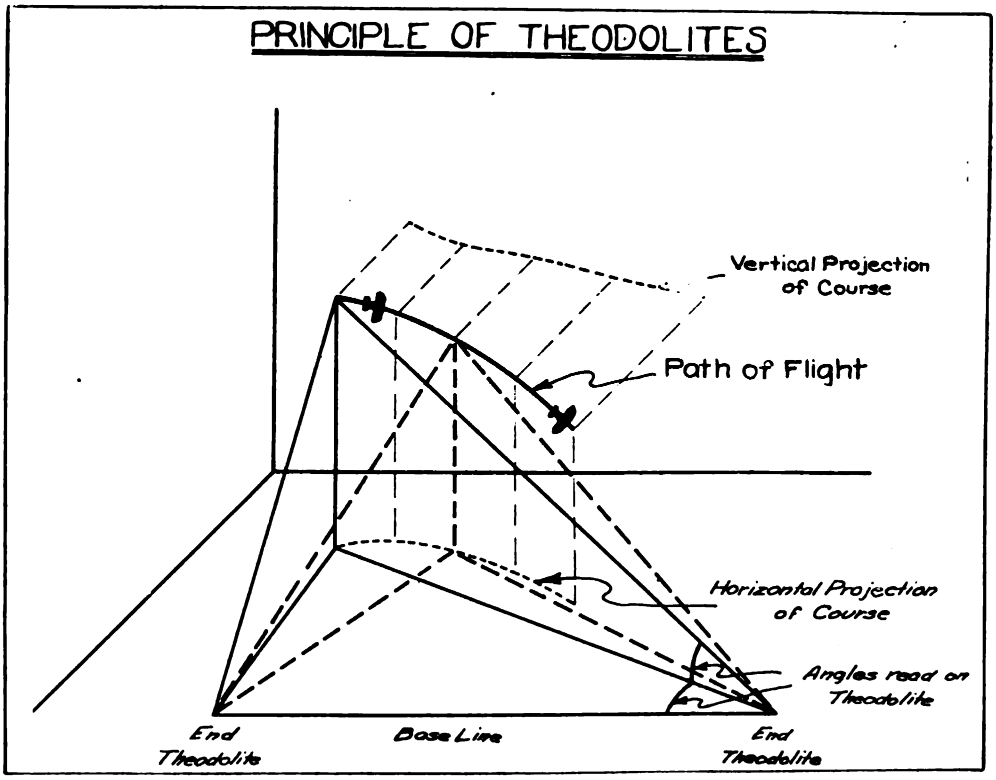

PRINCIPLE OF THEODOLITES
Vertical Projection of Course
Path of Flight
Horizontal Projection of Course
Angles read on Theodolite
End Theodolite
Base Line
End Theodolite

FIG. 1

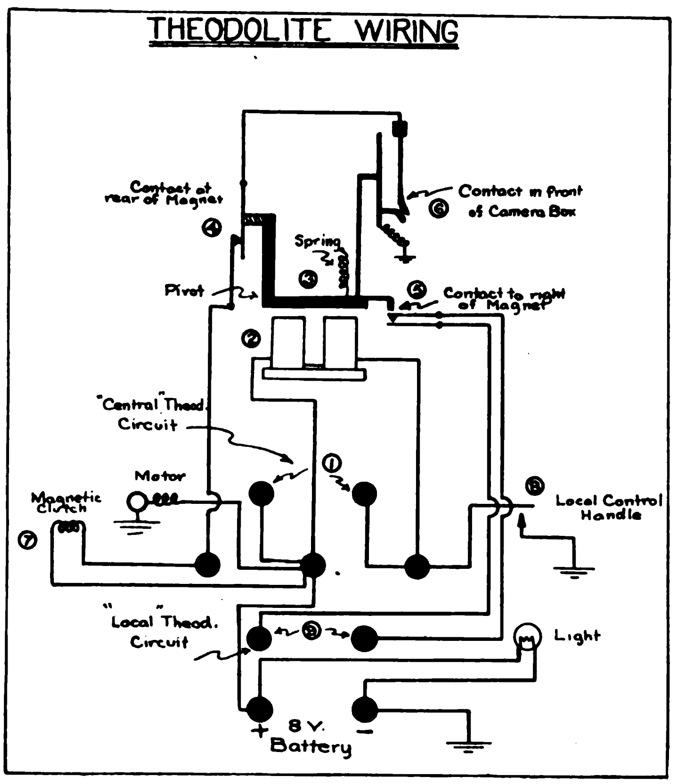

THEODOLITE WIRING
Contact at rear of Magnet
Contact in front of Camera Box
Spring
Pivot
Contact to right of Magnet
"Central" Theod. Circuit
Motor
Magnetic Clutch
Local Control Handle
"Local" Theod. Circuit
Light
+
8 V.
Battery
−

FIG. 2.

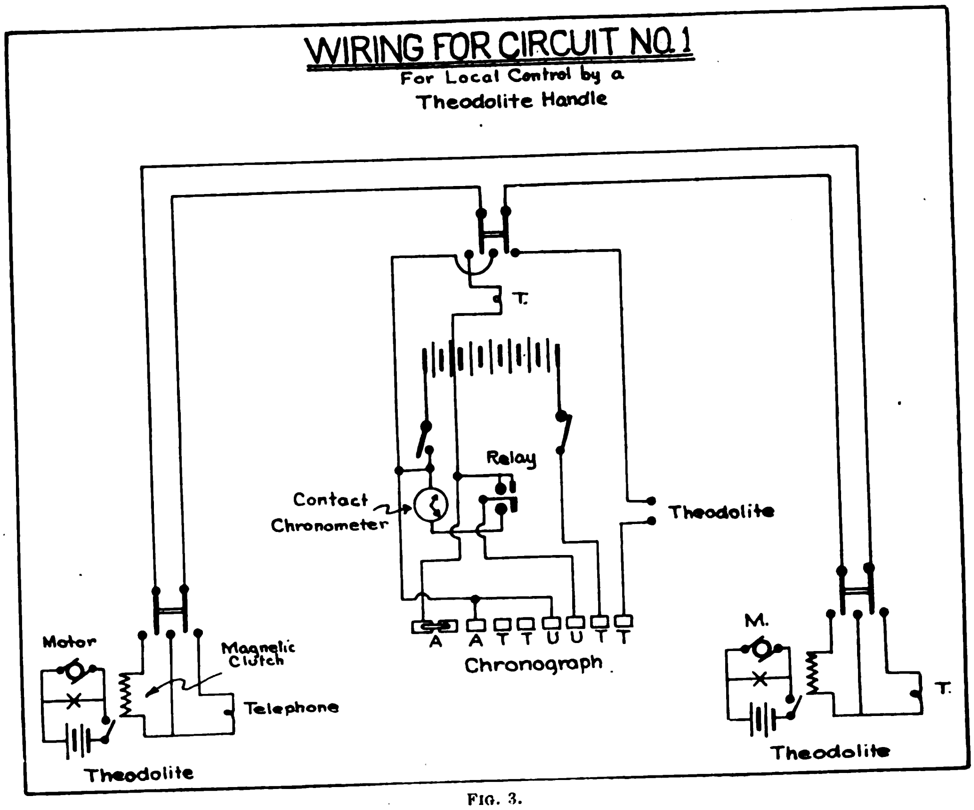

WIRING FOR CIRCUIT NO. 1
For Local Control by a
Theodolite Handle
T.
Relay
Contact
Chronometer
Theodolite
Motor
Magnetic
Clutch
Telephone
A A T T U U T T
Chronograph
M.
T.
Theodolite
Theodolite

FIG. 3.

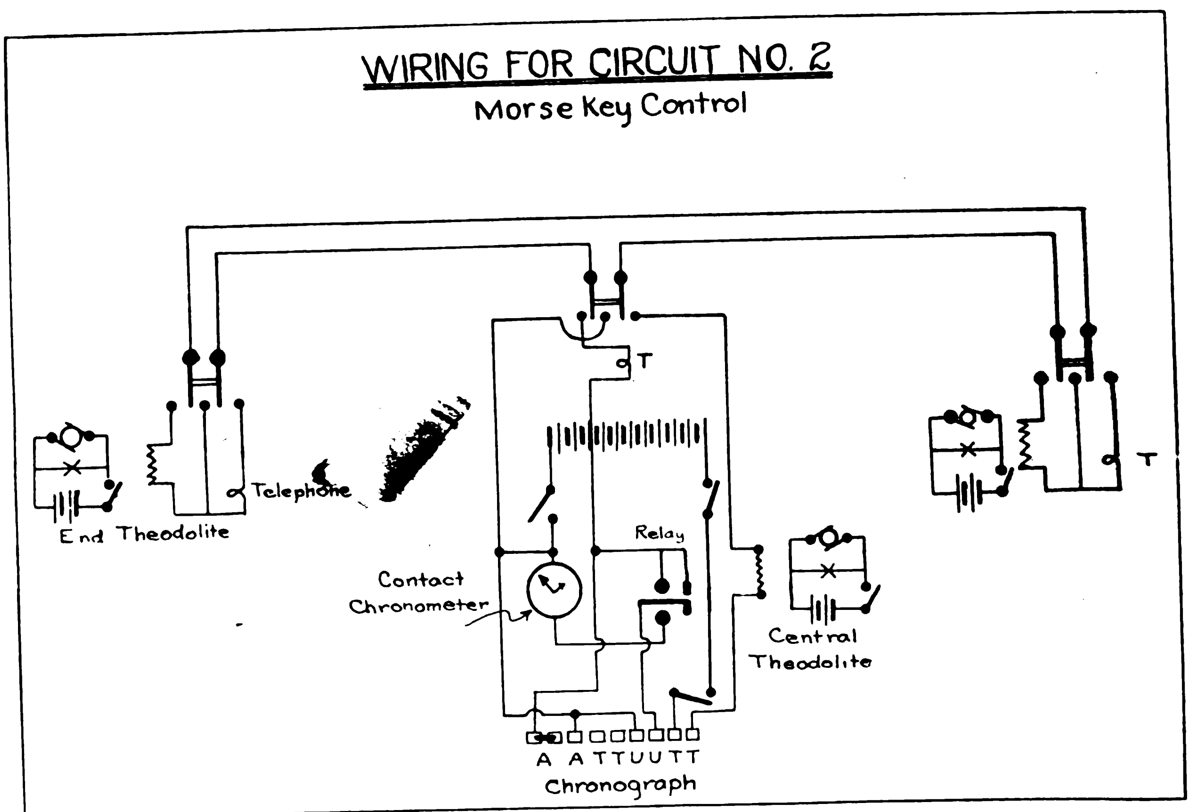

WIRING FOR CIRCUIT NO. 2
Morse Key Control
T
Telephone
End Theodolite
T
Relay
Contact
Chronometer
Central
Theodolite
A A T T U U T T
Chronograph

FIG. 4.

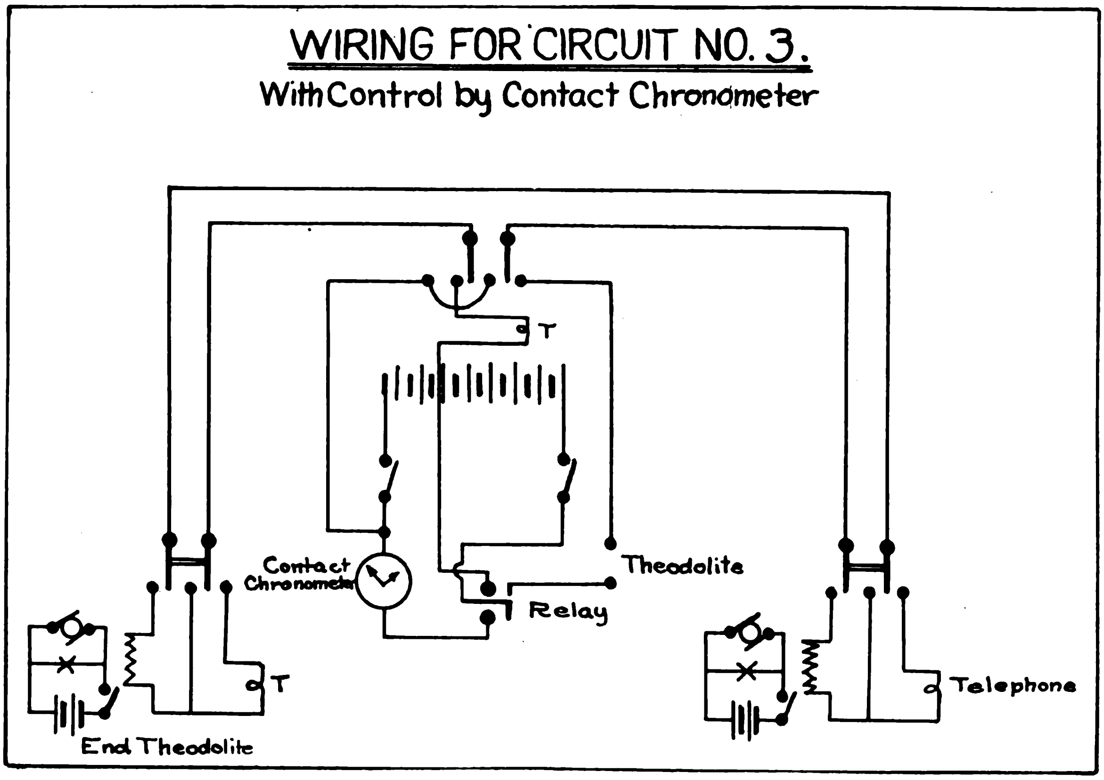

WIRING FOR CIRCUIT NO. 3.
With Control by Contact Chronometer
T
Contact Chronometer
Theodolite
Relay
T
End Theodolite
Telephone

Fig. 5.

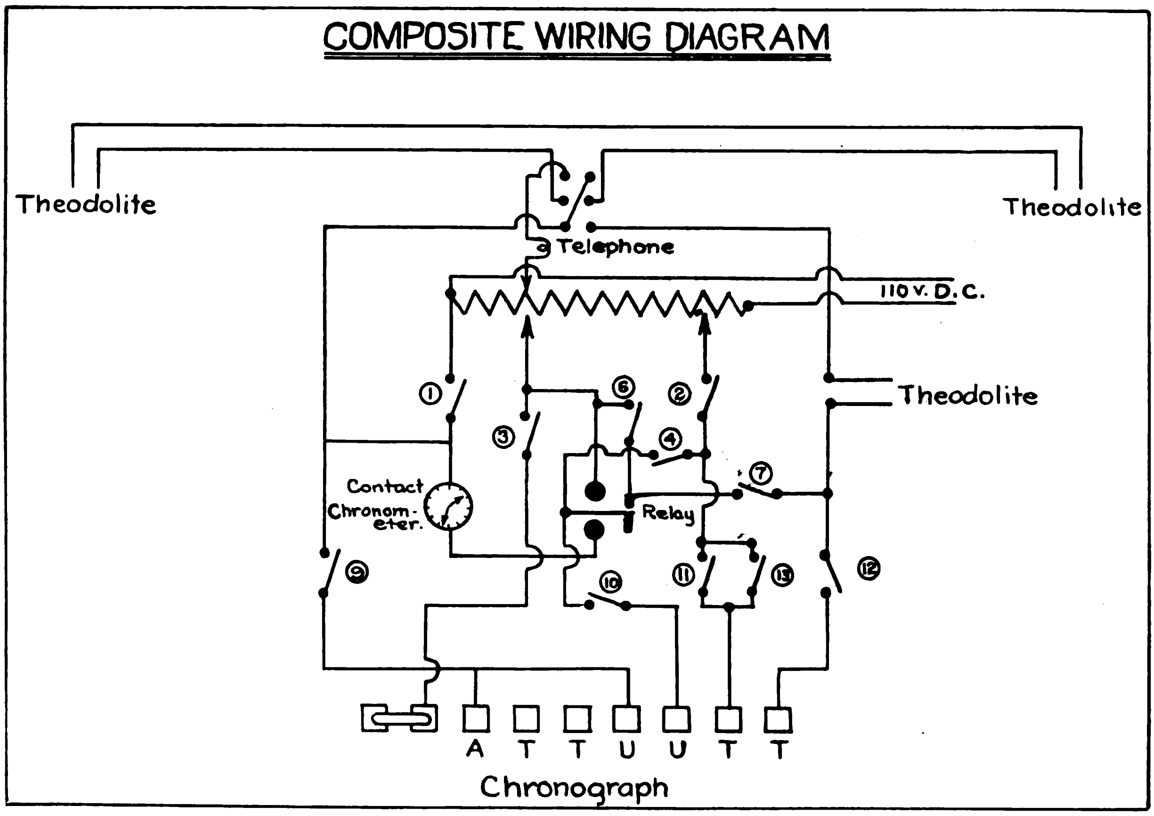

COMPOSITE WIRING DIAGRAM
Theodolite
Theodolite
Telephone
110 V. D.C.
Theodolite
Contact Chronom-eter.
Relay
A T T U U T T
Chronograph

Fig. 6.

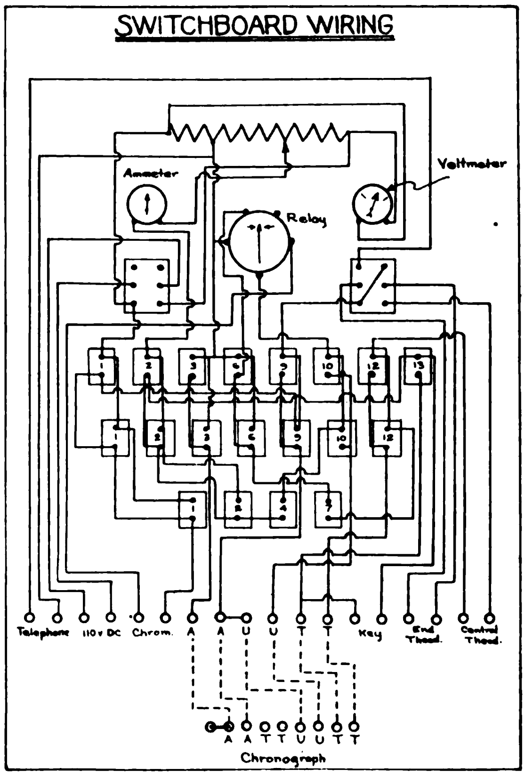
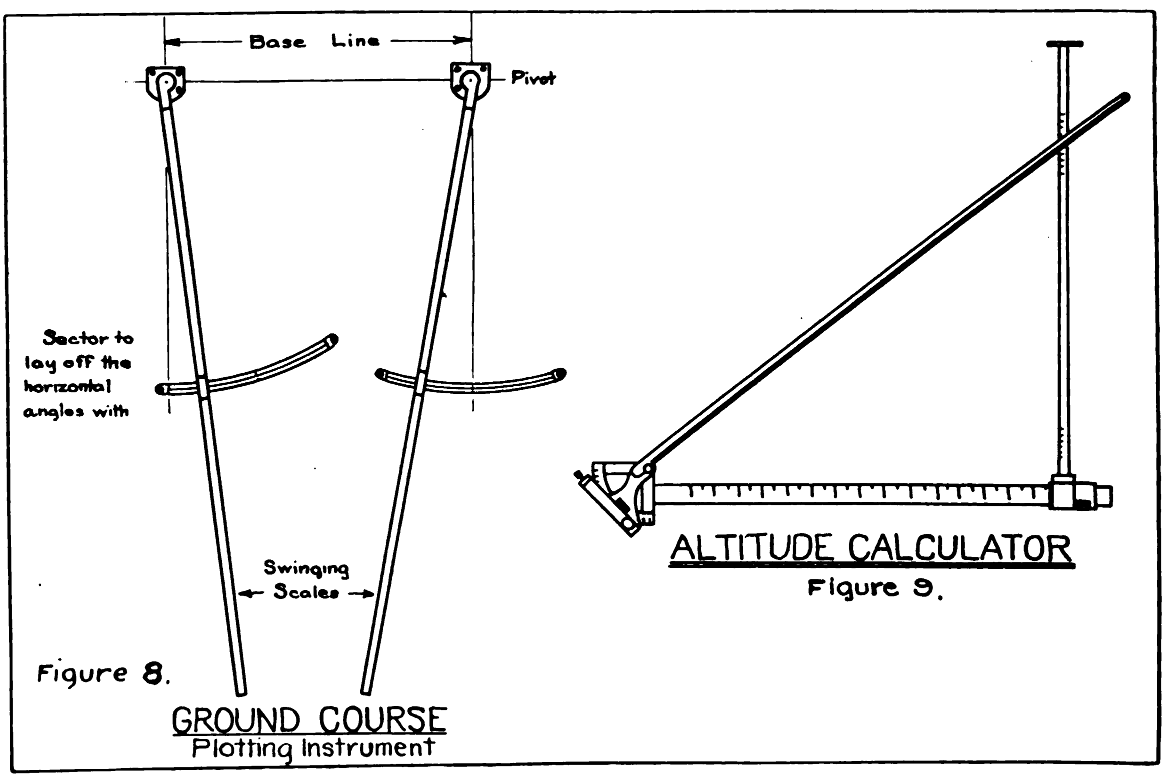


Fig. 7.



Figs. 8 and 9.

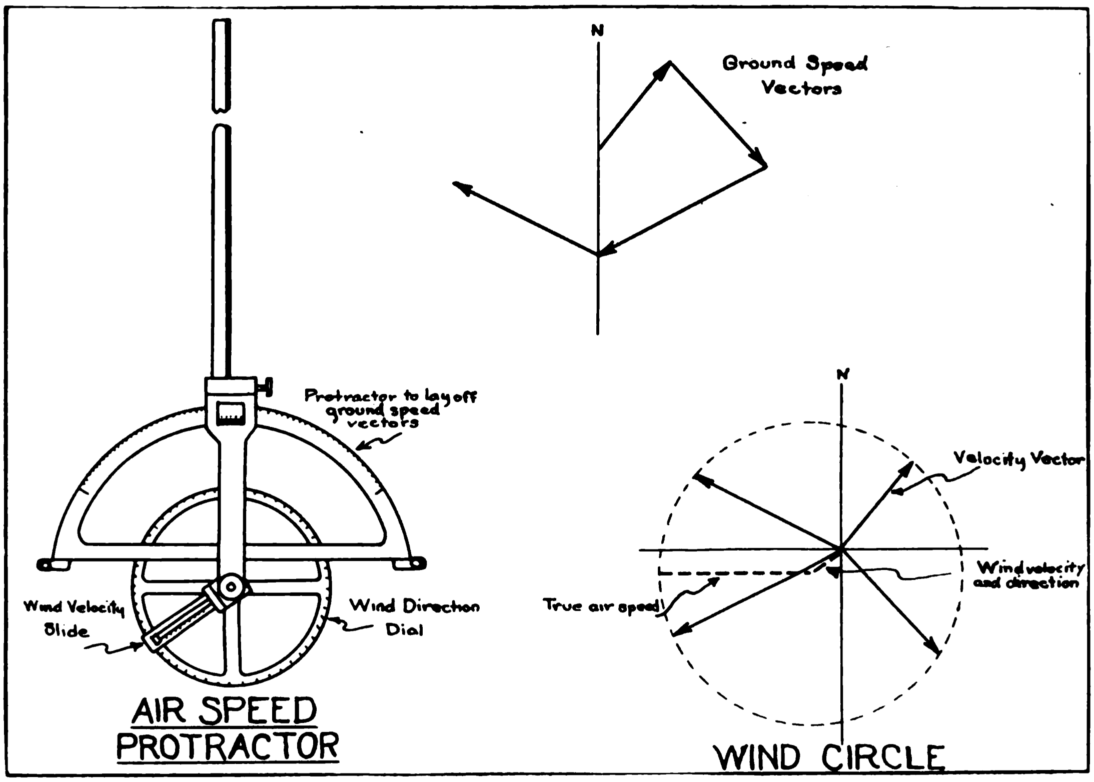

N
Ground Speed
Vectors
Protractor to lay off
ground speed
vectors
Wind Velocity
Slide
Wind Direction
Dial
AIR SPEED
PROTRACTOR
N
Velocity Vector
Wind velocity
and direction
True air speed
WIND CIRCLE

FIG. 10.

CONFIDENTIAL

File D 52.1/D.H.4/129 McCOOK FIELD REPORT, SERIAL No. 2010

AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV February 15, 1923 No. 398

FUEL CONSUMPTION DURING CLIMB—DH-4B WITH LIBERTY 12-A ENGINE AND FORM "D" SUPERCHARGER

(POWER PLANT SECTION REPORT)

Prepared by David Gregg
Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 15, 1922

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

CERTIFICATE: By direction of the Secretary of War the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

TEST OF SUPERCHARGER AIR COOLERS.

OBJECT OF TEST.

The object of this test is to compare relative cooling effect of the three types of air coolers which have been tested with the Form "D" supercharger.

CONCLUSIONS.

The small honeycomb air cooler (Drawing No. X-34098) offers no advantage [1] over the General Electric tubular type and has a somewhat greater pressure drop. The large honeycomb air cooler (Drawing No. X-38520) increases the cooling approximately 40 per cent with a proportional increase in area. While this air cooler is somewhat larger than necessary for flights up to 20,000 feet, it is recommended for use for all high altitude work or in special cases where increased cooling is necessary.

DESCRIPTION OF SUPERCHARGER AIR COOLERS.

The small honeycomb air cooler consists of a radiator core 4 inches by 15 inches by 9 inches made up of extruded copper tubes 0.268 inch in diameter and 0.313 inch across the hex, fitted in a sheet brass shell which conducts the air to the carburetor intakes. The weight of this air cooler averages about 36 pounds.

In the large honeycomb air cooler, which is similar in construction to the small one, the core is 15¼ inches by 5$\frac{13}{16}$ inches by 9 inches and the radiator tubes of which it is composed has the hex head increased from 0.313 inch to 0.323 inch, giving more area between the tubes and decreasing the pressure drop through the core. This air cooler is shown in figures 3, 4, and 5, and weighs 37 pounds. The increased size of this air cooler, without the increased weight, was obtained by elimination of several soldered seams and a general refinement in design.

The tubular or General Electric air cooler, figure 6 (General Electric Drawing No. W-124315) consists of forty-two ¾ inch O. D. steel tubes welded into two steel plates $\frac{3}{16}$ inch thick. The weight of this air cooler is approximately 30 pounds, but an air header must be used to connect the two carburetor intakes. This brings the total weight of the air cooler up to approximately 37 pounds.

METHOD OF TEST.

Distance type thermometers were installed in the supercharger air outlet and the carburetor air intake, the difference between these two readings giving the temperature drop through the air cooler. The pressure drop through the air cooler was measured on a mercury manometer.

The curves shown in figure 1 were plotted from the average of a number of flights to 20,000 feet under varying conditions and indicate the increased cooling effect of the large honeycomb air cooler of the other types.

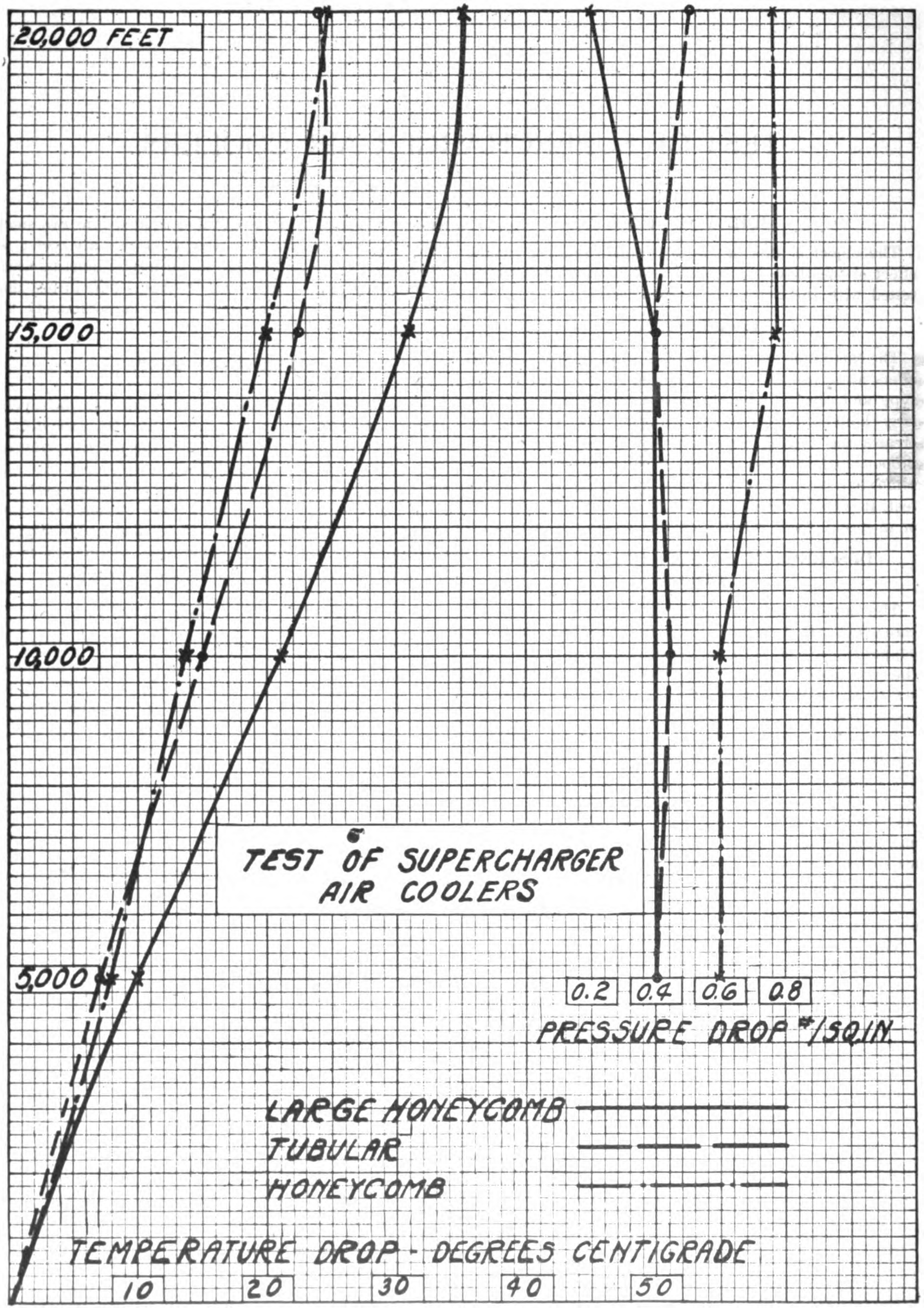
RELATIVE COOLING EFFECT.

The curve in figure 2 shows the temperature drop per square foot of radiating surface. In this respect the large and small honeycomb radiators are almost identical; the increase in temperature drop in the larger being directly proportional to the increase in radiating area. The tubular type air cooler gives from 80 to 90 per cent greater radiation per square foot of surface than the honeycomb types. This is undoubtedly due to the better air flow around the tubes, the radiator cores on the honeycomb types being blanketed to a certain extent by their proximity to other parts of the engine.

The effective cooling area to the different types are as follows:

Small honeycomb	sq. ft.	37.5
Large honeycomb	do.	55.5
Tubular	do.	21.5

[1] That is, from the point of view of cooling effect. The honeycomb air cooler permits better vision, and offers slightly less head resistance.



20,000 FEET
15,000
10,000
5,000
TEST OF SUPERCHARGER AIR COOLERS
0.2
0.4
0.6
0.8
PRESSURE DROP #/SQ.IN.
LARGE HONEYCOMB
TUBULAR
HONEYCOMB
TEMPERATURE DROP - DEGREES CENTIGRADE
10
20
30
40
50

FIG. 1.

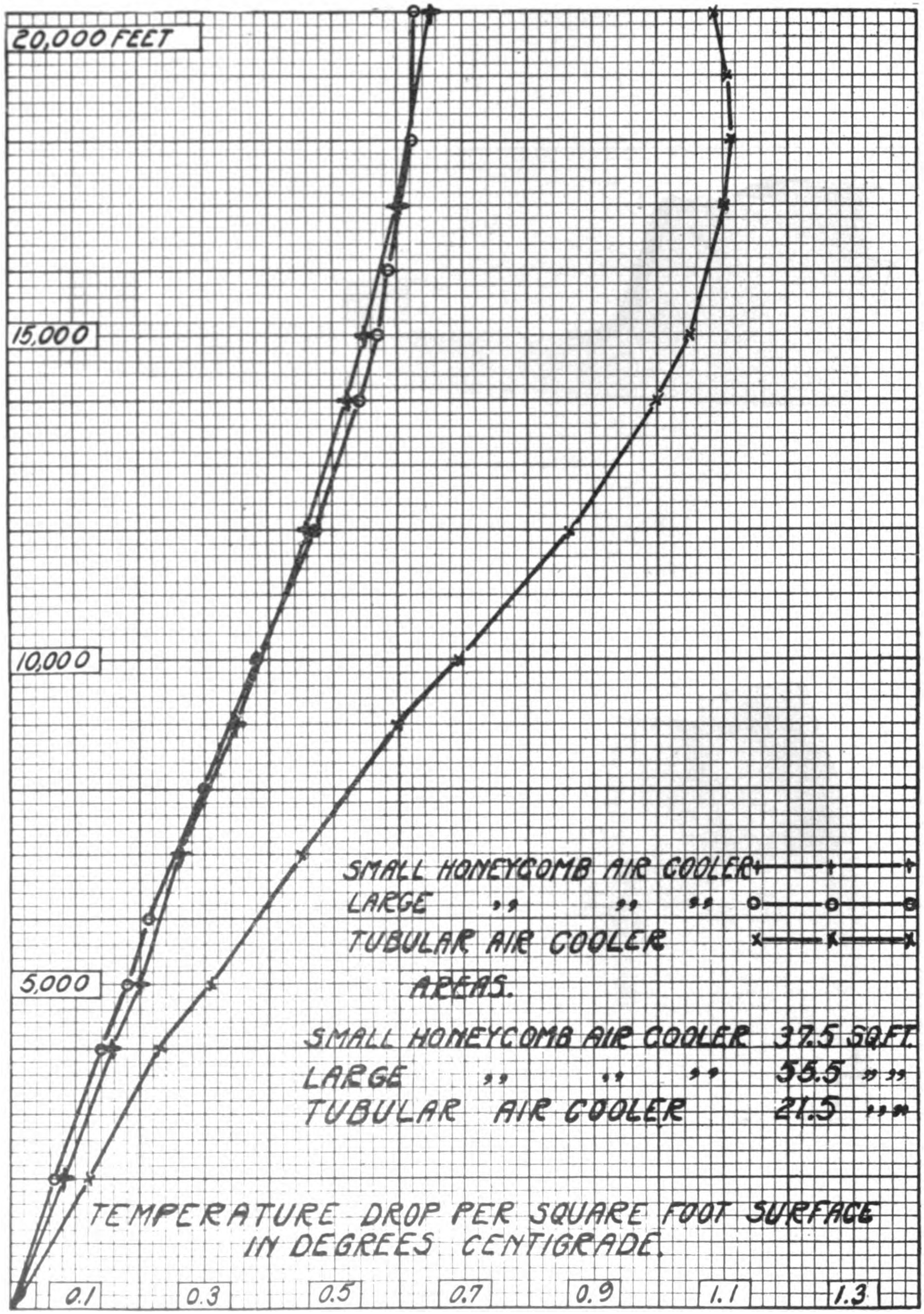

20,000 FEET
15,000
10,000
5,000
SMALL HONEYCOMB AIR COOLER
LARGE " " "
TUBULAR AIR COOLER
AREAS.
SMALL HONEYCOMB AIR COOLER 37.5 SQ.FT.
LARGE " " " 55.5 " "
TUBULAR AIR COOLER 21.5 " "
TEMPERATURE DROP PER SQUARE FOOT SURFACE
IN DEGREES CENTIGRADE.
0.1
0.3
0.5
0.7
0.9
1.1
1.3

Fig. 2.

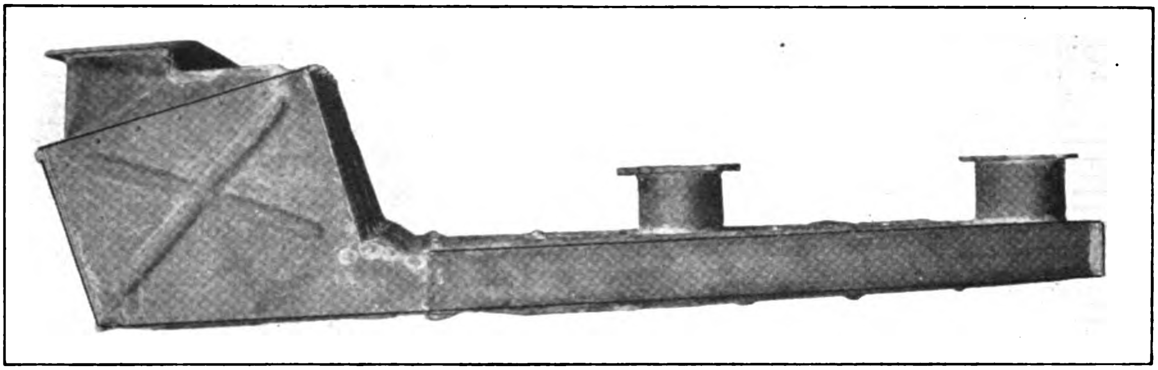


FIG. 3.—Large honeycomb air cooler—side view

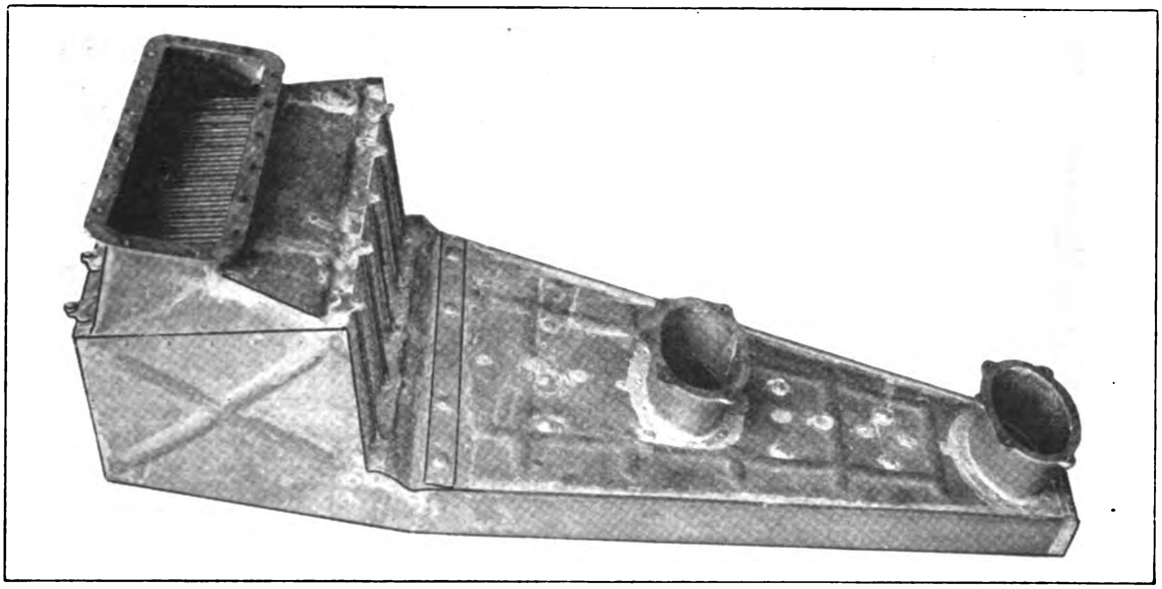


FIG. 4.—Large honeycomb air cooler—three-fourths bottom view.

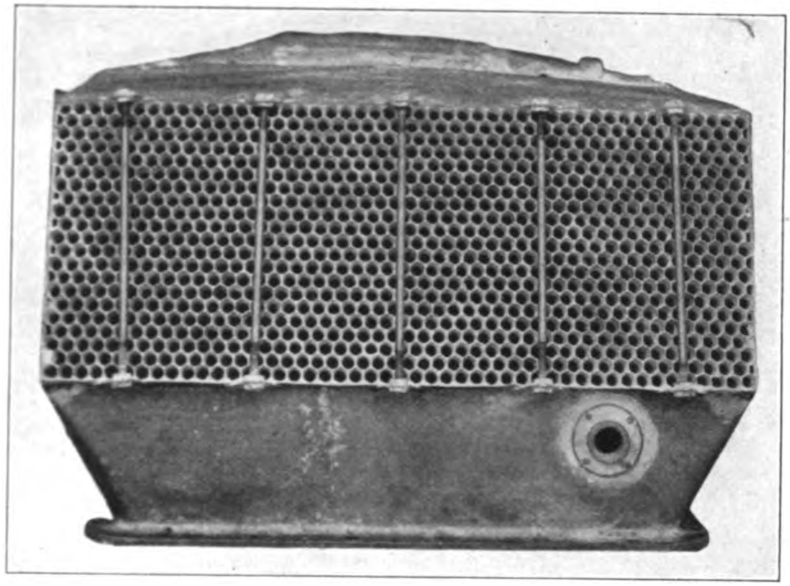


FIG. 5.—Large honeycomb air cooler—front view.

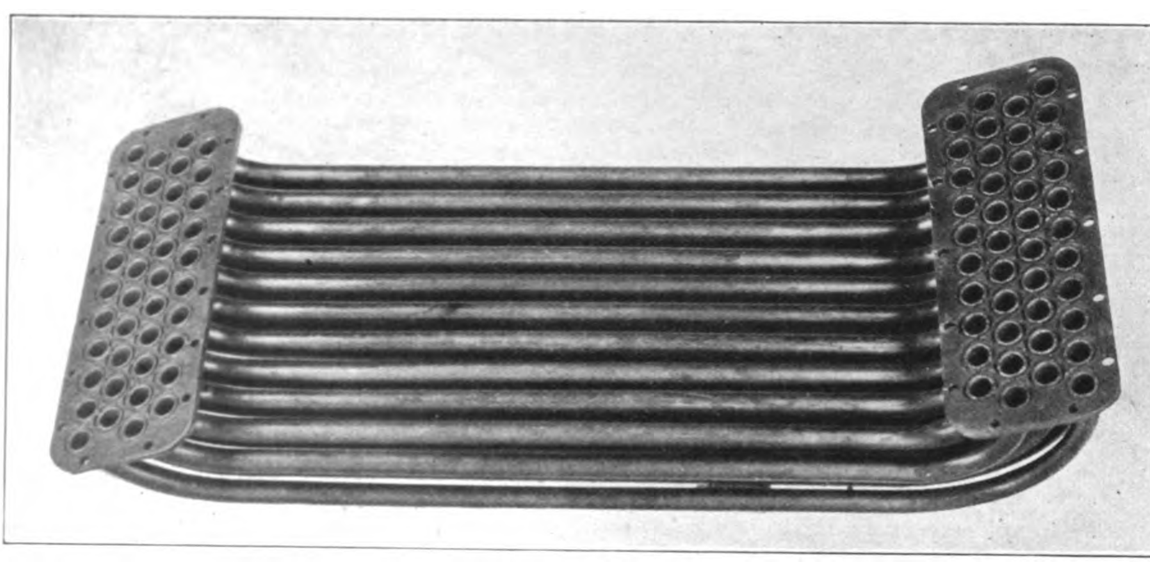


FIG. 6.—General Electric tubular air cooler.

O